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ANALYSIS AND PROGRAMMING FOR RESEARCH IN THE PHYSICS OF THE UPPER ATMOSPHERE

James N. Bass
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Frank R. Roberts
Edward C. Robinson

Logicon, Inc.
18 Hartwell Avenue
Lexington, Massachusetts 02173

Final Report
1 January 1980 - 9 January 1982

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AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS 01731

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Computer Program	Jacchia 1977 Density Model	Statistical Filtering
Diffusion Equation	Orbit Determination	Thrust Model

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A versatile density model for the upper atmoshpere (DENMOD) has been developed to provide quantitative density data. This software package consolidates recent atmospheric density models for convenient usage. Computations in the Jacchia 1977 Model have been streamlined. Methods are presented for comparative evaluations of various recent atmospheric density models, such as those included in DENMOD, with respect to the precision of satellite position predictions. These comparisons are benchmarked by accurate satellite tracking data obtained from CW Doppler beacon measurements.

Block 20 (Continued)

AFGL ephemerides systems are described which provide efficient calculations of satellite orbits expressed in a variety of forms. The utility of these programs has been expanded by adding the capability for performing ancillary calculations. These include evaluation of occultation conditions and viewing conditions for configurations of multiple observing platforms. With addition of magnetic field models which include field line tracing routines, these software systems can be used to evaluate the time-histories of various types of geomagnetic images (or footprints) of satellites as they traverse their orbits.

Improvements have been made in the AFGL Rocket Trajectory System, a software system which provides statistical filtering of radar data for rocket launches. New rocket types have been added to the system's repertoire of thrust models.

Acknowledgement

The support and guidance of Mr. Robert E. McInerney, Data Systems Section Chief, and Ms. Eunice C. Cronin, Computer Center Branch Chief, are greatly appreciated.

Thanks are also due to the various AFGL investigators, with whom we have been associated, whose motivation and direction have consistently benefitted our participation in AFGL research. The encouragement and technical advice of Dr. Kenneth S.W. Champion, Atmospheric Structure Branch Chief, was especially helpful in the development of the analytic and condensed versions of the Jacchia 1977 atmospheric density model and in the interpretation of density variation inferred from the analysis of Doppler beacon tracking data.

Mr. Donald E. Cozzens and Ms. Eileen M. Mitchell *contributed substantially* to the development of software.

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1.0 Atmospheric Density Models

Knowledge of neutral upper atmospheric densities is an important requirement for the understanding and analysis of many phenomena under study at AFGL. Researchers in many areas desire best estimates of composition and temperatures as inputs to models and data analysis programs. Prominent examples are analyses of auroral, airglow and ionospheric measurements.

The continuing need for accuracy in satellite tracking and ephemerides prediction also results in the need for improved modeling of thermospheric density variations. A case in point concerns the SKYLAB, whose orbit decayed at a faster rate than predicted, due to the substantial increase in solar activity in the current cycle. Recently the solar flux reached such high levels as to cause temporary loss of tracking of an 800km satellite. Rapid density variations during magnetic storms continue to limit satellite tracking and prediction accuracy, particularly at lower altitudes.

Density modeling research has thus continued at a high level. During the period of this contract, updates were made to the Jacchia 1977[1] and MSIS[2] models, based on continued analysis of mass spectrometer data. These will undoubtedly be further updated as new data becomes available. In particular discrepancies have been found between MSIS temperatures and recent measurements [3] which may be reduced by the use of revised and new incoherent scatter data from the Millstone Hill Radio Observatory.

Support of AFGL efforts has included the following:

1. Development of a software package of existing recent models for convenient usage by researchers in both density modeling and other fields.

2. Development of analytic and condensed versions of the Jacchia 1977 density model.

3. Comparative evaluations of satellite positional prediction accuracies.

4. Studies of density variations by analysis of Doppler beacon tracking data.

1.1 Density Model Package

Program DENMOD provides a convenient means to compute neutral thermospheric densities and temperatures from recent models. Input may be from cards or a satellite ephemeris file. Output consists of a printout with options for storage on other devices.

As shown in Figure 1, the package consists of the main program DENMOD, an output routine OUTDEN and the density computation software headed by subroutine DENS. The latter software may by itself be easily incorporated into other programs if users desire. The appropriate calling parameters are defined in the listings. The functions of the subroutines shown in Figure 1 are described in Section 1.1.2.

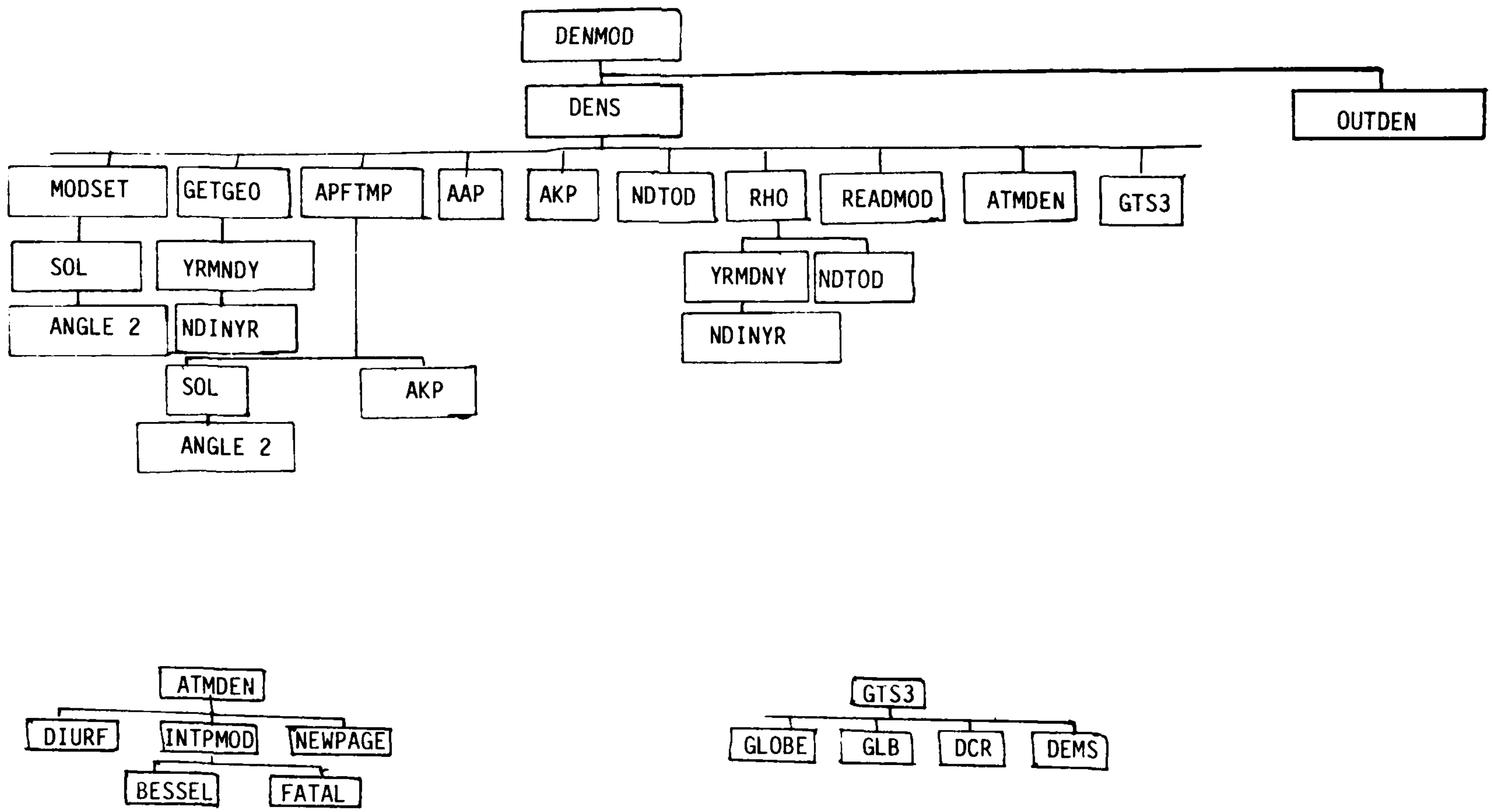

Figure 1. Structure of Density Model Package

1.1.1 Functional Description

Program DENMOD allows one to compute, for selected time and positions, any or all of the following properties

- Mass Density
- Constituent densities
- Exospheric temperature
- Local temperature
- Solar and geophysical parameters

The following models are available:

1. U.S.S.R. - Cosmos[4]
2. Jacchia 1977[1]
3. MSIS longitude averaged[2]
4. MSIS with longitude/UT variations[5]

The user provides time and position input in either of two modes.

1. Ephemeris file (TAPE1) in LOKANGL format[6] (refer also to section 2.1.5)
2. Cards. In this case a range of heights may be specified for a single time on one input card.

In either mode the user has the option to directly input geophysical information (solar and geomagnetic activity) or have the program obtain this from tables on TAPE2.

In addition to printouts, the results optionally may be saved on binary (TAPE3) and/or card image BCD (TAPE4), the latter being convenient for transmittal to non-CDC installations.

For the Jacchia 1977 model a special mass storage input file, JSDM, is required, which contains tables of temperatures and constituent densities an functions of altitude and exospheric temperature.

Figure 2 and Table 1 define the inputs required and the output files produced. A sample printout is shown in Figure 3.

```
      PROGRAM DENMOD(INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4,JSDM)
C
C  LOGICON,INC.                                      AUGUST,1979
C  DENSITY MODEL PACKAGE FOR FOLLOWING MODELS
C    USSR-COSMOS (ELYASBERG, ET. AL., SPACE RES. XII, P. 727, 1972)
C    JACCHIA 1977 (JACCHIA, SAO SPECIAL REPORT #375, 1977)
C    MSIS LONGITUDE AVERAGED (HEDIN, ET. AL., J. GEOPHYS. RES. 82,
C      P. 2139, 1977)
C    MSIS WITH LONGITUDE/UT VARIATIONS (HEDIN, ET. AL., J. GEOPHYS. RES.
C      84, P. 1, 1978)
C
C  TAPE1 = EPHEMERIS FILE
C  TAPE2 = AP/F10.7 FILE
C  TAPE3 = BINARY OUTPUT FILE
C  TAPE4 = BCD OUTPUT FILE
C  JSDM  = JACCHIA 1977 MASS STORAGE FILE
C
      DIMENSION APF10(3),IDNPAR(2)
      DIMENSION IDL(5,2),TLIM(2),A(253),IA(253)
      EQUIVALENCE(A,IA)
      COMMON/OUTDEN/ID(5),SEC,POS(3),DEN(15,4),JOUT(11),JMOD(4),TITLE(8)
     1,NLINE,JOUTP,JIN
      DIMENSION LIST(6)
      DATA LIST/3*-1,0,2*-1/
      DATA TLIM/0.,1.E10/
C
C  INPUT PARAMETERS
C      CARD#   COL      FORMAT  VARIABLES
C      1       1-80     8A10    TITLE(1-8)
C                                PRINTOUT PAGE TITLE
C      2       3        I1      JIN  TIME/POSITION INPUT MODE
C                                     1=EPHEMERIS FILE (TAPE1), 2=CARDS
C      2       6-16     11I1    JOUT(1-11)
C                               OUTPUT INDICATOR FOR ITH VARIABLE
C                               1=YES,0=NO
C                                  1. MASS DENSITY(GM/CM3)
C                                  2. O2 DENSITY(/CM3)
C                                  3. O DENSITY (/CM3)
C                                  4. N2 DENSITY(/CM3)
C                                  5. N DENSITY (/CM3)
C                                  6. HE DENSITY(/CM3)
C                                  7. AR DENSITY(/CM3)
C                                  8. H DENSITY (/CM3)
C                                  9. EXOSPHERIC TEMPERATURE(DEG K)
C                                 10. LOCAL TEMPERATURE (DEG K)
C                                 11. GEOPHYSICAL DATA AND SOLAR EPHEMERIS
C                                     GEOMAGNETIC INDEX(AP)
C                                     INSTANTANEOUS SOLAR FLUX(F10.7)
C                                     SMOOTHED SOLAR FLUX(F10.7 BAR)
C                                     SOLAR RIGHT ASCENSION(DEG)
C                                     SOLAR DECLINATION(DEG)
C      2       18-20    I3      JOUTP
C                                OTHER OUTPUT FILES
C                                 0=NONE,1=BCD ONLY,2=BINARY ONLY,3=BOTH
C      2       28-31    4I1     JMOD(1-3)
C                                MODEL INDICATORS(1=YES,0=NO)
C                                  1. USSR-COSMOS
```

Figure 2a. DENMOD Input/Output

```
C                                  2. JACCHIA 1977
C                                  3. MSIS LONGITUDE AVERAGED
C                                  4. MSIS WITH LONGITUDE/UT VARIATIONS
C      (FOR JIN=1)
C     3      1-3     I3     IDL(1,1)  MONTH   EARLIEST TIME
C     3      4-6     I3     IDL(2,1)  DAY       TO COMPUTE
C     3      7-11    I5     IDL(3,1)  YEAR        DENSITIES
C     3      12-14   I3     IDL(4,1)  HOUR
C     3      15-17   I3     IDL(5,1)  MINUTE
C                                     IF IDL(1,1) .LE. 0 COMPUTATION
C                                        STARTS WITH 1ST DATA RECORD
C                                        ON EPHEMERIS FILE.
C     3      21-23   I3     IDL(1,2)  MONTH   LATEST TIME
C     3      24-26   I3     IDL(2,2)  DAY       TO COMPUTE
C     3      27-31   I5     IDL(3,2)  YEAR        DENSITIES
C     3      32-34   I3     IDL(4,2)  HOUR
C     3      35-37   I3     IDL(5,2)  MINUTE
C                                     IF IDL(1,2) .LE. 0 COMPUTATION
C                                        ENDS WITH LAST DATA
C                                        RECORD ON FILE
C     3      41-70   3F10.3 APF10(1-3)
C                             1. INSTANTANEOUS SOLAR FLUX(F10.7)
C                             2. SMOOTHED SOLAR FLUX(F10.7 BAR)
C                             3. AP
C                             IF APF10(1) .LE. 0. ALL 3 VALUES WILL BE
C                               OBTAINED FROM TABLES ON TAPE2.
C      (FOR JIN=2)
C     3-N    2-3     I2     IMO( -1 TERMINATES)
C     3-N    5-6     I2     IDA
C     3-N    8-11    I4     IYR
C     3-N    13-14   I2     IHR
C     3-N    16-17   I2     IMN
C     3-N    18-23   F6.1   POS(1) - GEOCENTRIC LATITUDE(DEG N)
C     3-N    24-29   F6.1   POS(2) -WEST LONGITUDE(DEG)
C     3-N    30-36   F7.1   POS(3) - LOWEST HEIGHT(KM)
C     3-N    38-42   F5.3   DH - HEIGHT INCREMENT(KM)
C     3-N    43-47   I5     NH - NUMBER OF HEIGHTS
C     3-N    49-53   F5.1   APF10(1) - INSTANTANEOUS SOLAR FLUX(F10.7)
C     3-N    55-59   F5.1   APF10(2) - SMOOTHED SOLAR FLUX (F10.7 BAR)
C     3-N    61-65   F5.1   APF10(3) - AP
C                             IF APF10(1) .LE. 0., THEN ALL 3 VALUES
C                             WILL BE TAKEN FROM TAPE2 TABLES.
C     3-N    66-70   I5     IPG  START OUTPUT ON NEW PAGE IF =1
C
C
C  TAPE1 INPUT--SEE AFGL-TR-78-0204 (LOGICON,INC.,FINAL REPORT,1978),P19
C
C
C  TAPE2 INPUT--1 RECORD PER DAY STARTING AT LEAST 85 DAYS BEFORE
C               EARLIEST DENSITY COMPUTATION TIME
C
C  WORD NUMBER      COLUMNS        FORMAT        DESCRIPTION
C    1              1-8            F8.0          AP FOR 0-3 HRS UT
C    2              9-16           F8.0          AP FOR 3-6 HRS
C    3              17-24          F8.0          AP FOR 6-9 HRS
C    4              25-32          F8.0          AP FOR 9-12 HRS
C    5              33-40          F8.0          AP FOR 12-15 HRS
```

Figure 2b. DENMOD Input/Output (Continued)

```
C     6               41-48          F8.0            AP FOR 15-18 HRS
C     7               49-56          F8.0            AP FOR 18-21 HRS
C     8               57-64          F8.0            AP FOR 21-24 HRS
C     9               65-72          F8.0            DAILY F10.7 AT 17 HRS
C    10               73-77          I5              MODIFIED JULIAN DAY
C                                                    (1/1/73=41683)
C
C   USDM INPUT--SEE DOCUMENTATION
C
C
C   TAPE3 BINARY OUTPUT
C
C   RECORD 1                         HEADER: (TITLE(I),I=1,8)
C
C   DATA RECORDS
C
C   WORD NUMBER                      DESCRIPTION
C     1                              MONTH(INTEGER)
C     2                              DAY(INTEGER)
C     3                              YEAR(INTEGER - LAST 2 DIGITS)
C     4                              HOUR(INTEGER)
C     5                              MINUTE(INTEGER)
C     6                              SECONDS(REAL)
C     7                              GEOC. LATITUDE,DEG N(REAL)
C     8                              LONGITUDE,DEG W(REAL)
C     9                              HEIGHT,KM(REAL)
C    10                              NIMOD - NUMBER OF MODELS IN OUTPUT
C                                       (INTEGER)
C   11 THRU 10+NIMOD                 (IMOD(I),I=1,NIMOD) - CODES IDENT-
C                                       IFYING THESE MODELS (INTEGER) (SEE
C                                       BELOW)
C   11+NIMOD                         NJDEN - NUMBER OF VARIABLES IN OUTPUT
C                                       (INTEGER)
C   11+NIMOD+1 THRU                  (JDEN(J),J=1,NJDEN) - CODES
C     11+NIMOD+NJDEN                    IDENTIFYING THESE VARIABLES
C                                       (INTEGER) (SEE BELOW)
C   11+NIMOD+NJDEN+1                 ((A(JDEN(J),IMOD(I)),J=1,NJDEN),
C       THRU                            I=1,NIMOD) - RESULTS FOR THESE
C     11+NIMOD+NJDEN+NJDEN*NIMOD        VARIABLES AND MODELS(REAL)
C
C
C   TAPE4 BCD OUTPUT
C   RECORD 1  SAME AS FOR BINARY(8A10)
C
C   DATA RECORDS
C
C   SAME AS FOR BINARY, EACH SPLIT INTO 3 OR MORE LINES
C   LINE NUMBER            WORDS                        FORMAT
C     1                    1-9                          12X,2(I2,1H/),I2,3I3,
C                                                        F7.1,F6.1,F8.1
C     2                    10 THRU 11+NIMOD+NJDEN       21I3
C     3 THRU               12+NIMOD+NJDEN               1P7E11.3
C   2+(NIMOD*NJDEN)/7         THRU
C                          11+NIMOD+NJDEN+NJDEN*NIMOD
C
C
C   MODEL CODES                 VARIABLE CODES
C   1. USSR-COSMOS               1. MASS DENSITY
C   2. JACCHIA 1977              2. O2 DENSITY
C   3. MSIS LONGIT. AVERAGED     3. O DENSITY
C   4. MSIS+LONGITUDE/UT         4. N2 DENSITY
C                                5. N DENSITY
C                                6. HE DENSITY
C                                7. AR DENSITY
C                                8. H DENSITY
C                                9. EXOSPHERIC TEMPERATURE
C                               10. LOCAL TEMPERATURE
C                               11. GEOMAGNETIC INDEX
C                               12. INSTANTANEOUS SOLAR FLUX
C                               13. SMOOTHED SOLAR FLUX
C                               14. SOLAR RIGHT ASCENSION
C                               15. SOLAR DECLINATION
C
C
```

Figure 2c. DENMOD Input/Output (Continued)

Record Number 1

Word #	Symbol	Description
1	LABEL	BCD label
2-9	TITLE	80 Character BCD
10	TMINMOD	Minimum exospheric temp. in table
11	TMAXMOD	Maximum exospheric temp.
12	NTSTEP	Number of Temperature steps
13	DTMOD $\left[= \frac{(TMAXMOD - TMINMOD)}{NSTEP}\right]$	Temperature step size
14	NREG (≤ 7)	Number of height regions (=number of subsequent records)
15	NSUM	Unused
16-23	$ALZSTEP_i$	Natural logs of boundaries (km) of height regions.
24-30	$NZSTEP_i$	Number of height steps in each region
31-37	$ALDZ_i$ $\left[= \frac{(ALZSTEP_{i+1} - ALZSTEP_i)}{NZSTEP_i}\right]$	Step size in natural log of height in each region.
38	GNMOD	Gravitational acceleration at Earth surface (km/sec^2)
39	RNMOD	Earth radius (km)
40	RSTAMOD	Universal gas constant
41	AVOGMOD	Avogadro's number
42	NSPMOD (=7)	Number of species
43-49	$AMWMOD_i$	Molecular masses of species
50-56	$MODRLEN_i$ $[=(NSPMOD+1) * (NTSTEP+1) * (NZSTEP_i+1)]$	Lengths of subsequent records

The species will be given in the order:

O_2, O, N_2, N, He Ar, H

Table 1. Format of Mass Storage File "JSDM"

Record Number IREG+1 1≤IREG<NREG)

Word #	Description
1	Local temperature of height exp [ALZSTEP(IREG)] and exospheric temperature TMINMOD
2 thru NSPMOD+1	Logs base 10 of number densities (m^{-3}) for molecular species at this height and exospheric temperature.
NSPMOD+2 thru (NTSTEP+1)* (NSPMOD+1)	Repeat of words 1 thru NSPMOD+1 for this height and equally spaced exospheric temperatures TMINNOD + DTMOD thru TMAXMOD
(NTSTEP+1)*(NSPMOD+1)+1 thru MODRLEN (IREG)	Repeat of words 1 thru (NTSTEP+1)*(NSPMOD+1) for remaining heights exp [ALZSTEP (IREG) + I *ALDZ (IREG)] I = 1 thru NZSTEP (IREG)

Table 1. Format of Mass Storage File "JSDM" (continued)

EXCEDE II SPECTRAL

MODELS: 2=JACCHIA 1977 3=MSIS LONG AVERAGED

MO/DA/YR	HR	MN	SC	LAT DEG	W.LON DEG	HEIGHT KM	MASS DEN GM/CM3	O2 DEN /CM3	O DEN /CM3	N2 DEN /CM3	AR DEN /CM3	TLOC DG K	MODEL
10/19/79	5	47	0	65.1	147.5	107.0	1.791E-10	5.672E+11	2.996E+11	2.996E+12	2.520E+10	226	2
10/19/79	5	47	0	65.1	147.5	107.0	HEIGHT OUT OF RANGE FOR MODEL 3						
10/19/79	5	47	0	65.1	147.5	108.0	1.505E-10	4.589E+11	2.791E+11	2.523E+12	1.999E+10	233	2
10/19/79	5	47	0	65.1	147.5	108.0	HEIGHT OUT OF RANGE FOR MODEL 3						
10/19/79	5	47	0	65.1	147.5	109.0	1.266E-10	3.708E+11	2.590E+11	2.128E+12	1.592E+10	242	2
10/19/79	5	47	0	65.1	147.5	109.0	HEIGHT OUT OF RANGE FOR MODEL 3						
10/19/79	5	47	0	65.1	147.5	110.0	1.068E-10	2.995E+11	2.395E+11	1.799E+12	1.273E+10	251	2
10/19/79	5	47	0	65.1	147.5	110.0	HEIGHT OUT OF RANGE FOR MODEL 3						
10/19/79	5	47	0	65.1	147.5	111.0	9.039E-11	2.425E+11	2.206E+11	1.526E+12	1.024E+10	262	2
10/19/79	5	47	0	65.1	147.5	111.0	HEIGHT OUT OF RANGE FOR MODEL 3						
10/19/79	5	47	0	65.1	147.5	112.0	7.682E-11	1.972E+11	2.027E+11	1.299E+12	8.282E+09	273	2
10/19/79	5	47	0	65.1	147.5	112.0	HEIGHT OUT OF RANGE FOR MODEL 3						
10/19/79	5	47	0	65.1	147.5	113.0	6.561E-11	1.614E+11	1.858E+11	1.110E+12	6.743E+09	285	2
10/19/79	5	47	0	65.1	147.5	113.0	HEIGHT OUT OF RANGE FOR MODEL 3						
10/19/79	5	47	0	65.1	147.5	114.0	5.635E-11	1.333E+11	1.702E+11	9.539E+11	5.529E+09	297	2
10/19/79	5	47	0	65.1	147.5	114.0	HEIGHT OUT OF RANGE FOR MODEL 3						
10/19/79	5	47	0	65.1	147.5	115.0	4.868E-11	1.112E+11	1.559E+11	8.238E+11	4.565E+09	310	2
10/19/79	5	47	0	65.1	147.5	115.0	HEIGHT OUT OF RANGE FOR MODEL 3						
10/19/79	5	47	0	65.1	147.5	116.0	4.230E-11	9.366E+10	1.428E+11	7.153E+11	3.797E+09	323	2
10/19/79	5	47	0	65.1	147.5	116.0	HEIGHT OUT OF RANGE FOR MODEL 3						
10/19/79	5	47	0	65.1	147.5	117.0	3.697E-11	7.963E+10	1.310E+11	6.244E+11	3.180E+09	336	2
10/19/79	5	47	0	65.1	147.5	117.0	HEIGHT OUT OF RANGE FOR MODEL 3						
10/19/79	5	47	0	65.1	147.5	118.0	3.248E-11	6.829E+10	1.203E+11	5.477E+11	2.681E+09	349	2
10/19/79	5	47	0	65.1	147.5	118.0	HEIGHT OUT OF RANGE FOR MODEL 3						
10/19/79	5	47	0	65.1	147.5	119.0	2.868E-11	5.902E+10	1.106E+11	4.827E+11	2.274E+09	362	2
10/19/79	5	47	0	65.1	147.5	119.0	HEIGHT OUT OF RANGE FOR MODEL 3						
10/19/79	5	47	0	65.1	147.5	120.0	2.545E-11	5.135E+10	1.020E+11	4.273E+11	1.940E+09	375	2
10/19/79	5	47	0	65.1	147.5	120.0	1.816E-11	2.713E+10	1.410E+11	2.770E+11	1.444E+09	384	3
10/19/79	5	47	0	65.1	147.5	121.0	2.267E-11	4.494E+10	9.414E+10	3.798E+11	1.664E+09	388	2
10/19/79	5	47	0	65.1	147.5	121.0	1.589E-11	2.333E+10	1.269E+11	2.409E+11	1.214E+09	407	3
10/19/79	5	47	0	65.1	147.5	122.0	2.027E-11	3.953E+10	8.707E+10	3.388E+11	1.435E+09	402	2
10/19/79	5	47	0	65.1	147.5	122.0	1.403E-11	2.026E+10	1.151E+11	2.115E+11	1.031E+09	430	3
10/19/79	5	47	0	65.1	147.5	123.0	1.819E-11	3.493E+10	8.068E+10	3.033E+11	1.242E+09	415	2
10/19/79	5	47	0	65.1	147.5	123.0	1.249E-11	1.774E+10	1.051E+11	1.871E+11	8.847E+08	452	3

Figure 3. Sample DENMOD Printout

1.1.2 Mathematical or Logical Procedures

The main program first reads cards 1 and 2 to determine the output header, input mode, and outputs requested.

If the time/position input mode indicates the existence of an ephemeris file, card 3 is then read to give the earliest and latest times requested and the geophysical parameters to apply for entire run (unless APF10(1) $\leq$ 0). The dates and times are then converted to modified Julian dates,and fractions thereof, and stored in the array TLIM, unless the months are 0, in which case the values 0 and 10^{10} are stored in TLIM. The first record on the file is skipped and a loop is entered. In each pass a data record is read and the time converted to modified Julian date and fraction. If this is less than TLIM (1), the program goes to the next record. If it is greater than TLIM (2), or the end of the data is reached, the program terminates. Otherwise subroutine DENS is called to perform the requested calculations, and the results are passed to subroutine OUTDEN for output.

For card input the procedure is similar, except that;

1) Each card is processed until the card with IMO=-1 is encountered, causing termination.
2) The modified Julian date is not computed in the main program, but rather in subroutine MODSET via the call to DENS.
3) If the IPG parameter is set, the main program sets the common variable NLINE=0; this will cause subroutine OUTDEN to start a new page.

Subroutine OUTDEN is the output module. The appropriate data is passed to it through the common block /OUTDEN/. On the first call an initialization phase is executed. This includes the construction of an execution time format statement, which depends on which variables are to be included in the printout, and the storage of the total number of variables for the BCD and binary output files, if these latter are requested.

On each call OUTDEN outputs all requested variables for all requested models, for a particular time and position. A decrementing line counter NLINE keeps

track of the number of lines left on the current page. Setting NLINE to 0 automatically triggers a new page. This can be done by the main program since NLINE is in the common block /OUTDEN/.

Subroutine DENS is the main computation subroutine, returning up to 15 variables (mass density, composition, etc.) for a single call for a particular time, position and model. The position (subroutine MODSET) is converted from geographic to inertial coordinates using[7]

$$Rg = 1.746647719 + 6.30038809863056d + 0.5064 \times 10^{-14}d^2$$

to obtain Rg, the right ascension of Greenwich, where d is the time elapsed in days since 1 Jan., 1950, 0 hr UT. Terms due to nutation, included in Ref. 7, are neglected here. The elements of the Sun are computed (SOL) from standard expressions.[8] From these the solar coordinates are obtained as follows:

- True Anomoly:

$$v=m + (2e-.25e^3)\sin m + 1.25e^2 \sin 2m + 1.08e^3 \sin 3m$$

where

e = eccentricity
m = mean anomoly

- Sun-Earth distance (astronomical units):

$$R=(1-e^2)/(1+e \cos v)$$

Mean longitude of Sun (apparent);

$$L= v + w - 20.47''/R \quad (0 \leq L \leq 2\pi)$$

where

w = mean longitude of perihelion

- Right ascension:

$$\gamma = \tan^{-1} (\tan L \cos E) + \pi \cdot I\left[(L+\pi/2)/\pi\right]$$

where

E = obliquity
I(X) = largest integer $\leq$ X

- Declination

$$\delta = \tan^{-1}\left[\sin E \sin L/\sqrt{1-\sin^2 E \sin^2 L}\right]$$

If geophysical values are not given directly they are obtained by subroutine GETGEO from tables maintained internally containing up to 100 days of data read from TAPE2 as necessary by subroutine APFTMP. Instantaneous values required for the Jacchia 1977 model are obtained by interpolation through the two closest tabular points in time. The tabular points for geomagnetic index ap are assumed to be 1.5 hr, 4.5 hr etc. on each day, for solar activity 17 hr (noon Ottawa time). A similar procedure is implemented for the U.S.S.R. - Cosmos model except that a constant value period is assumed, centered at each tabular point, during which the index is assumed constant at the tabular value, with linear interpolation between these regions. The constant value period is 45 minutes for ap and 6 hours for F10.7, the 10.7 cm. solar flux. Delay times Δt in days are applied to the time at which each index is computed in accordance with the model specifications:

	Jacchia 1977	U.S.S.R. - Cosmos
F10.7	$1.26 + 0.37\sin(H-92°)$	1.0
ap	$0.1 + 0.2\cos^2\phi$	0.25

where H is the solar hour angle (right ascension at point - right ascension of Sun), and ϕ is the geomagnetic latitude computed by the simple dipole approximation (Ref. 1). The MSIS models do not require instantaneous values, simply using the daily measured F10.7 for the previous day and the daily average ap (commonly referred to as Ap) for the current day.

Smoothed F10.7 is assumed constant for a given day, computed as the average over 6, 6 and 3 solar rotations centered on the given day for the U.S.S.R. - Cosmos, J77, and MSIS models respectively. If the data does not extend sufficiently beyond the day, the latest available data is used. A diagnostic is printed in this case. The average is corrected for variable Earth-Sun distance R by multiplying each daily value by R^2 prior to averaging, and dividing the resulting average by R^2.

The individual models are then computed as described in the previously mentioned references, (function RHO for the U.S.S.R. - Cosmos model, subroutine ATMDEN for the Jacchia 1977 model, subroutine GTS3 for the two MSIS models), with the following notes for the Jacchia 1977 model.

1) The geomagnetic activity thermal component for each constituent, $\Delta \log n_i$, is computed by

$$\Delta\log n_i = \beta_i \left(\frac{800}{T_\infty}\right)^m \left(.0054z + \frac{.21}{1 + .0002(z-130)^2} - .717\right) \sinh^{-1}(.003\Delta T_\infty)$$

z = height

$m = 1.7\tanh(.005(z-100))$

$\beta_{O_2} = 1.16$

$\beta_O = 0.52$

$\beta_{N_2} = 1.00$

$\beta_{He} = 0.10$

$\beta_{Ar} = 1.49$

$\beta_H = 0.00$

$\beta_N = 0.46$

ΔT_∞ = correction to exospheric temperature due to geomagnetic activity

T_∞ = exospheric temperature for zero geomagnetic activity

2) The "J71 model", Eqs 40-44 of Ref. 1 is used for the semiannual variation

3) Atomic Nitrogen is included in the formulation. Pertinent parameters are:

Fractional Sea-level Volume = 0.00007494

Molecular Weight = 14.0067

(homopause height change effect) = -3.70×10^{-3}

Seasonal latitudinal parameter = -0.22

Modification 3, above, reflects updates to the model by Jacchia since publication of Ref. 1, based on recent mass spectrometer data[9,10]. These modifications are discussed in more detail later.

For easy reference, the functions of all of the routines shown in Figure 1, including those mentioned in the preceding paragraphs, are briefly summarized in the following:

DENMOD: Input and control

DENS: Control of density model computation

OUTDEN: Output

MODSET: Conversion of time and position to internal values (modified Julian date, right ascension, declination)

GETGEO: Tabular look up and interpolation of solar and geomagnetic activity indices

APFTMP: Construction of internal tables of solar and geomagnetic activity indices from data on file (TAPE2)

AAP: Conversion from geomagnetic activity index Kp to geomagnetic activity index ap

AKP: Conversion from geomagnetic activity index ap to geomagnetic activity index Kp

NDTOD: Computation of the day number of the year from the date.

RHO: U.S.S.R.-Cosmos density model computation

READMOD: Initialization for subsequent access to mass storage file JSDM, used for the Jacchia 1977 model

ATMDEM: Jacchia 1977 density model computation

GTS3: MSIS density model computation

SOL: Solar ephemeris computation

ANGLE2: Conversion of an angle to a value in the interval $(0, 2\pi)$

YRMNDY: Computation of the calendar date from the modified Julian date

NDINYR: Determination of the number of days in the year (365 or 366)

DIURF: Computation of Jacchia 1977 diurnal variations.

INTPMOD: Tabular look up of Jacchia 1977 model densities and local temperatures, as functions of height and exospheric temperature

BESSEL: Two dimensional interpolation

FATAL: Printout of fatal error messages (inadequate Jacchia 1977 tables)

NEWPAGE: Skip to new page for detailed Jacchia 1977 printout. This detailed printout option is currently inactive, but may be activated by setting the logical variable DEBUG in the common block GENINFO to .TRUE.

GLOBE, GLB: Computation of MSIS global, height independant variations

DCR: Computation of departures from diffusion equilibrium in MSIS models

DEMS: Computation of MSIS height profiles

1.1.3 Model Comparisons and Usage

1.1.3.1 U.S.S.R.- COSMOS

The U.S.S.R.- Cosmos model is an empirical model for total mass density only, based on analysis of orbital decay of Cosmos satellites in the 160-300 km region. The authors believe the model to be valid up to 600 km, as they have tried to relate nighttime and diurnal variations to the Jacchia 1970 model.[11] The range of solar activity coverage is limited to values of 75-150 in the customary units of 10^{-22} $w/cm^2/Hz$. The principal advantage of this model is its simplicity in computation. Mass density is computed directly from simple functions without requiring computation of temperature and component densities, as with the other models. Extensive functional representations (as in the MSIS models) and table look-up/ interpolation (as in Jacchia 1977 model to compute diffusion equation solutions) are avoided.

1.1.3.2 Jacchia 1977

The Jacchia 1977 (J77) model is the first of the Jacchia series to include mass spectrometer measurements (largely OGO-6 and ESRO-4). Otherwise, as with previous models, the J77 model is based mainly on satellite orbital decay, largely above 200km. However it covers a broad range of solar activity. In addition to total mass density, seven component densities (O_2, O, N_2, N, He, Ar, H), exospheric temperature, and local temperature are computed.

Geomagnetically quiet vertical temperature profiles are defined as functions of exospheric temperature, which in turn is a function of solar activity, solar and geographic declination and local time. Component densities are generated from this, assuming homogeneous mixing from 90km to 100km, with corrections for O_2 dissociation, and molecular diffusion above 100km. To account for observed differences in local time phases among the components, different exospheric temperatures are used. Corrections to the logs of component densities are made for geomagnetic activity, seasonal-latitudinal, and semiannual effects. Exospheric and local temperatures are also corrected for geomagnetic activity.

The J77 model has the best coverage over the various geographical and geophysical conditions and is particularly suitable for active conditions. A particular weakness is in the low altitude tidal (local-time) behavior. It is known that these tidal variations switch from predominantly diurnal above 300km to predominently semidiurnal below 140km [12], while the J77 tidal behavior remains predominantly diurnal at low altitudes. This is probably caused by the predominance of data above 200km in the data base.

1.1.3.3 MSIS

The MSIS models are based on in-situ mass spectrometer composition data and incoherent scatter temperature data. The satellites range in height from 160km to 600km. The data covers the 1966-1976 solar cycle (peak solar activity = 150 x 10^{-22} $W/M^2/Hz$). Vertical temperature and composition profiles are defined above a lower boundary at 120km with parameters (exospheric temperature, lower boundary temperature and gradient, and lower boundary composition) dependent on geographic and geophysical conditions. The latitudinal-tidal variations are expressed in spherical harmonics and are generally considered an improvement over the Jacchia representations. The diurnal to semidiurnal switchover at low altitudes, which the J77 model fails to represent, is present in the MSIS models. Nevertheless some aspects of equatorial variations are not reproduced, possibly a consequence of heavy weighting of middle latitudes in the data base.[13] Geomagnetic activity variations are represented through a highly nonlinear function of the activity index. However, since the daily average is used, short-term variations are not represented. Furthermore, J.W. Slowey[14] has pointed out a near-singularity in this function at the geographic poles for zero activity index.

The MSIS model with longitude/UT variations (sometimes called MSIS 78) is an extension of the original longitude averaged model by the addition of longitude/UT dependent terms, based purely on mass-spectrometer data, mostly above 190km. These terms appear significant mainly in the polar regions. Thus this version may be more accurate than the original MSIS in these regions, with no significant difference at the equator.

1.2 Computational Streamlining of the Jacchia 1977 Model

Due to the increasing complexity of Jacchia's recent density models[1] it becomes necessary to store, in tabular form, the solution of the diffusion equation for each constituent, even if only the total mass density is to be computed. This is because the models call for corrections to the diffusion process for such effects as local time phase variations, seasonal-latitudinal variations and geomagnetic activity, all of which differ for the different constituents. The Jacchia 1964 model[15], on the other hand, required only temperature corrections, and hence only the total mass density needed to be stored as a function of height and exospheric temperature. As a result, one must either set aside a large block of storage (the current SAO version of the Jacchia 1977 model would require in excess of 17,000 words), or resort to random access disk storage. The first approach is undesirable in almost all cases, particularly with small computers. The second poses problems in implementation on different computers.

Two approaches are presented here which take advantage of the fact that, with only two exceptions, all terms in the diffusion equation are analytically integrable. The exceptions are the scale height term, which differs for different constituents merely by a mass factor, and the vertical flux term for hydrogen, which is important only for low altitudes. It therefore is necessary to store only the integral of the common mass-independent factor of the former term, and the solution for hydrogen whenever that constituent is of special interest.

1.2.1 Condensed Tables

1.2.1.1 Analysis

The diffusion equation for the i^{th} constituent, in the Jacchia 1977 (J77) density model is[1,16]

$$\frac{dn_i}{n_i} + \frac{dT}{T}(1+\alpha_i) + \frac{dh}{H_i} + \frac{\Phi_i}{D}\frac{dh}{n_i} = 0$$

where

n_i = i^{th} constituent number density

T = temperature

α_i = i^{th} constituent thermal diffusion coefficient

$H_i = R^*T/M_i g$

h = height

$R^* = 8.31432 \times 10^3$ J(kg - mol)$^{-1}$/deg K

M_i = i^{th} constituent molecular mass

$g = 9.80665\,(1 + h/R_e)^{-2}$ m/sec^2

$R_e = 6.356766 \times 10^6$ meters

Φ_i = i^{th} constituent vertical flux

D = diffusion coefficient $= 2 \times 10^{20}\sqrt{T/N}$

N = total number density

The α_i are assumed values of -0.38 and -0.25 for helium and hydrogen and 0 for all others. The Φ_i are 0 for all but hydrogen. Neglecting the vertical flux term leads to[16]

$$n_i(h, T_\infty) = n_i(h_o, T_\infty)\left[\frac{T(h_o, T_\infty)}{T(h, T_\infty)}\right]^{1+\alpha_i} \exp\left[M_i\, F(h_o, h, T_\infty)\right]$$

where

$$F(h_o, h, T_\infty) = \int_{h_o}^{h} g(z)/R^*T(z, T_\infty)\, dz$$

T_∞ = exospheric temperature

1.2.1.2 Tabulation

In practice it is therefore necessary to tabulate only F and the density for one of the constituents at h_0 as a function of T_∞, if h_0 is chosen to be the homopause, 100km. If N_2 is chosen, then the others, except hydrogen, are given by

$$\log n_i (h_0, T_\infty) = \log n_{28} (h_0, T_\infty) + Q_i$$

where the subscript i indicates species by molecular weight and the Q_i are constants:

$$Q_i = \log (q_i/q_{28}) \quad i \neq 16, 32$$
$$Q_{16} = -\log q_{28} \; -\log (\bar{M}'/\bar{M}_0') + \log [2(1-\bar{M}'/\bar{M}_0')]$$
$$Q_{32} = -\log q_{28} \; -\log (\bar{M}'/\bar{M}_0') + \log \frac{\bar{M}}{\bar{M}_0'} \; (1 + q\ 32) -1$$

Where

q_i = sea level concentration of i^{th} constituent

$\bar{M}'$ = mean molecular mass at 100km (Eq. 5, ref. 1)
$\bar{M}_0'$ = mean molecular mass at sea level

If one is interested in including the escape flux term for hydrogen, special tables would still be necessary; however the storage requirement would still be considerably less than if separate tables are used for all constituents. Furthermore, since the escape flux term is important only below 500km, it would be necessary to store results only for that region. If one excludes the escape flux term, the H density is computed using: h_0 = 500km; eq. 17 of ref. 1:

$$\log n_1 (500, T_\infty) = 5.94 + 28.9\, T_\infty^{1/4};$$

and

$$F (500, h, T_\infty) = F (100, h, T_\infty) - F (100, 500, T_\infty).$$

1.2.1.3 Homogeneous Layer (90km < h < 100km)

For the homogeneous layer the diffusion equations are replaced by a single barometric equation for the mass density, from which component densities may be derived, as indicated in reference 1. Hence only the mass density need be stored. Alternatively one may store the density for N_2 and derive the others from it, as for the homopause boundary. The equations are the same except that $\overline{M}'$ would be the mean molecular weight at the height of interest, given by Eq. 5. of ref. 1.

1.2.1.4 Results

A subroutine has been constructed to implement the above procedures. Atomic nitrogen has been included, based on the most recent SAO subroutine version, which incorporates the AE OSS mass spectrometer data.[9,10] For this we have taken the fractional sea-level composition given by Table 2, with the resulting mean-molecular weight $\overline{M}_0 = \overline{M}_0' = 28.9586$.

Stored in the subroutine are tables for the diffusion function F along with the N_2 densities for the homogeneous layer and the atomic hydrogen solution including escape flux. Together these occupy less storage than required for a single height segment (4000 words) when the solutions are tabulated for each component on a random access file. Hence no external files are required. Run times on the CDC 6600 are comparable to the random access version, with essentially identical results.

Constituent	Fraction by Volume	Molecular Mass
Molecular Nitrogen (N_2)	0.78103	28.0134
Oxygen (O_2)	0.20953	31.9988
Argon (Ar)	0.009342	39.948
Helium (He)	0.000005242	4.0026
Atomic Nitrogen (N)	0.00007502	14.0067

Table 2. Sea-Level Composition

1.2.2 Analytic Representation of the Jacchia 1977 Model Atmosphere

Since a fully analytic solution for the temperature profiles specified in the Jacchia 1977 (J77) model is not possible it seems worthwhile to explore other forms. In particular the Jacchia - Walker (JW)profile suggested by Walker[17]:

$$T_{JW}(h,T_\infty) = T_\infty - (T_\infty - T_0)\, e^{-\sigma\xi}$$

leads to the solution

$$F(h_0\, h,\, T_\infty) = \frac{g_e R_e^2}{R^* (R_e + h_0)^2\, T_\infty} \left\{ \ln\left[\frac{T(h,\, T_\infty)}{T_0}\right] + \sigma\xi \right\}$$

where

$$\xi = (h - h_0)\,(R_e + h_0)/(R_e + h)$$

R_e = 6356.766km

g_e = gravitational acceleration at Earth's surface
= 9.80665 m/sec^2

$T_0 = T(h_0,\, T_\infty)$

σ = gradient parameter

For application :o the Jacchia 1977 model, it is prudent to choose h_0 = 125km, since this is the inflection point, although the various constituent densities at this height cannot be conveniently derived from one of them, as at 100 km. The gradient parameter may be chosen to fit the exact J77 profile in some fashion, such as to match the slope at 125km.

Results from this model deviate somewhat from the exact Jacchia 1977 model. In particular, for an exospheric temperature of 900K the local temperature deviation is 20K at 160km and the mass and argon densities differ by 6% and 12% at 225km.

To obtain better fits the form

$$T = [T_{JW}^{-1} + f]^{-1}$$

has been explored, where the function f is chosen to retain the closed-form integrability of the diffusion equation. In addition it is desirable that the resulting total temperature profile fit smoothly the exact J77 profile at $h = h_o = 125$km and maintain the inflection point character ($d^2T/dh^2 = 0$). It is evidently the lack of this latter characteristic which makes the simple JW form undesirable and possibly accounts for much of the error resulting from its use. These modifications lead to the following boundary conditions at $\xi = 0$.

$$f = df/d\xi = 0$$

$$d^2f/d\xi^2 = -G_o^2\zeta/T_o^2$$

where

$$G_o = dT/dh]_{h\,=\,h_o}$$

$$\zeta = \sigma + 2/(R_e + h_o) = G_o/(T_\infty - T_o) + 2/(R_e + h_o)$$

For convenience the functional form is chosen to have an exponentially decreasing character with parameters hopefully related to σ . One such form is

$$f = -\left[G_o\zeta/(2\beta_1^2 T_o^2)\right] f_{\beta_1}(\xi)$$

where

$$f_\beta(\xi) = e^{-\beta\xi}\left(1 - e^{-\beta\xi}\right)^2$$

and β is an adjustable parameter. To provide further flexibility the form

$$f(\xi) = -\left[G_o\zeta/(2\beta_1^2\ T_o^2)\right] f_{\beta_1}(\xi) + C_2\xi f_{\beta_2}(\xi)$$

has been chosen. The additional term $j = C_2\xi f_{\beta_2}$ satisfies

$$j = j' = j'' = 0$$

at $\xi = 0$.

For this profile the solution is given by

$$F(h_o, h, T_\infty) = F_{JW} + K\{C_1(\sum_{i=1}^{3} a_i\, q_1^{\,i} + 1/3)/\beta_1$$

$$+C_2 \left[\sum_{i=1}^{3} (\beta_2 \xi a_i - b_i)\, q_2^{\,i} + 11/18\right]/\beta_2^{\,2}\}$$

where F_{JW} = Jacchia-Walker solution (for T_{JW})

$c_1 = -G_o\ 5/(2$

$a_1 = -a_2 = -1;\ a_3 = -1/3$

$a_i = e$

$b_i = a_i/i$

$K = g_e R_e 2/[R^*(R_e + h_o)^2]$.

1.2.2.1 Results

The Fletcher-Powell non-linear function minimization method[18,19] has been used to determine the parameters β_1, β_2, c_2 to minimize the sum of the squared residuals

$$Q = \Sigma(T - T_{J77})^2$$

for T_∞ = 500, 700, 900, 1100, 1300, 1500, 1700, 1900. By inspection the results are found to be reasonably well represented by:

$T_\infty \leq 1100K$

$$\beta_1 = 2\sigma \left[1 + 10^{-4} (T_\infty - 800)\right]$$

$$\beta_2 = 0.0215 - 0.005 (T_\infty - 500)/200$$

$$C_2 = 10^{-5}(0.0566 - 0.08X + 0.04X^2); \; X = (T_\infty - 900)/200$$

$1100K \leq T_\infty \leq 1500K$

$$\beta_1 = 0.0385 - 0.012y + 0.0123y^2; \; y = (T_\infty - 1100)/400$$

$$\beta_2 = 0.0065 + 0.0167y$$

$$C_2 = 10^{-5}(0.0166 - 0.4548y^2)$$

$T_\infty \geq 1500K$

$$\beta_1 = 0.0388 - 0.0045z; \; z = (T_\infty - 1500)/400$$

$$\beta_2 = 0.0232 - 0.0040z$$

$$C_2 = -10^{-5} (0.4382 + 0.0387z)$$

Mass and constituent densities were computed using the Jacchia-Bass (JB) formulation presented here for the T_∞ region 500K -1900K at 100K steps and the height region 130km - 1000km at 10km steps. The results were compared with those from the exact J77 temperature profiles, except that vertical flux is ignored for H. Table 3 summarizes maximum % deviations for a 6-constituent gas (O_2, O, N_2, He, Ar, H) with the total mass density given by

$$\rho = \sum_{i=1}^{6} M_i \, n_i/A; \quad A = \text{Avogadro's Number}$$

It should be noted that a true J77 calculation would call for different exospheric temperatures for the different constituents to model the different diurnal phases; here all the n_i are computed for the same T_∞. Argon, with the largest mass, yields the largest disagreement among the constituents. The agreement is quite good, well within typical model-experiment differences such as those published by Forbes, Marcos and Gillette[20], and Sharp and Prag.[21] It should be noted that the maximum deviations are all within the 1100K - 1500K region, which proved to be the most difficult to fit. Outside this region all JB mass densities agree with J77 within 1% at all heights. Maximum temperature deviations are 13K at T_∞ = 1300K, h = 350km. Outside the 1100K-1500K region the maximum disagreement is 5K.

1.2.2.2 Conclusions

It has been shown that analytically solvable temperature profiles can be adjusted to realistically represent temperature - height variations above 125Km, allowing one to reduce tabular storage requirements and/or avoid the inconvenience of interpolation. It is therefore recommended that similar profiles be used in future atmospheric density modelling. The possibility of developing analytically integrable profiles below 125Km will be studied at a later date.

		TOTAL DENSITY	Ar DENSITY
h	300Km	1.1 ($h = 200$, $T_\infty = 1200$)	1.5 ($h = 190$, $T_\infty = 1200$)
h	500Km	2.1 ($h = 500$, $T_\infty = 1300$)	5.6 ($h = 500$, $T_\infty = 1300$)
h	1000Km	3.0 ($h = 750$, $T_\infty = 1300$)	8.5 ($h = 1000$, $T_\infty = 1300$)

Table 3. Maximum Absolute Value of JB-J77 Deviations (%)

1.3. Satellite Orbit Prediction Error Evaluations

Density Model evaluation by means of satellite orbit prediction errors has continued as part of an on-going effort to assist tracking and surveillance agencies in selection of models for performance of these functions. Although models also are evaluated in terms of their inherent accuracy compared with existing data [20,21], prediction accuracy evaluation should provide a more direct means of assessing a model's use in tracking. Calibration could be established between prediction accuracy and inherent accuracy. Furthermore prediction accuracy evaluation can be used to emphasize those variables important to a particular satellite of interest, such as geomagnetic activity, while de-emphasizing less important variables such as local time for a polar-orbiting satellite.

The principle software vehicles for these studies are Doppler beacon analysis program CELEST[22] and the radar data analysis package CADNIP/BADMEP[23]. This report will focus primarily on CELEST, although it substantially applies to CADNIP/BADMEP as well.

1.3.1 Procedures

The basic procedures have been described in previous reports (for example, Ref. 6). In summary, two CELEST runs are required per case. In the first run, data is fit over a selected span and the resulting trajectory extended by numerical integration over a subsequent predict span. In the second run data is fit over a span overlapping the first fit span and including data in the predict span in order to obtain a "true" trajectory to compare with the predicted trajectory obtained from the first run. In each run the fit is obtained by a least squares adjustment of Keplerian elements at the start of the fit span, and the drag coefficient for the whole fit span, the latter of which essentially acts as a scale factor to account for average error in the chosen density model. This procedure is repeated for several density models and time periods. Statistics (mean magnitude error, mean algebraic error, standard deviation) are then taken. Automated procedures[6] are used to simplify operations.

Time periods are chosen to reflect as nearly as possible overall variations in geomagnetic activity for low altitude satellites. Fit spans of one day followed by 15 hour prediction periods are generally sufficient to establish trends. Longer time spans are needed for higher altitude satellites. Care is taken to avoid orbit adjusts.

1.3.2 Program Changes

The MSIS 78 model has been added to CADNIP/BADMEP, replacing the Harris-Priester density model. Since, as previously noted, this model differs from the MSIS model only in terms based mainly on data above 190Km, the model has not been added to CELEST. Table 4 indicates the various models available in these programs. The NWL model is described in Ref. 24; and the Forbes-Garrett-Gillette model, in Ref. 25. Other models not previously discussed are described in Ref. 23 and references listed therein.

Calculation of solar and geomagnetic activity indices has been upgraded to include the linear interpolation scheme described in section 1.1.2 for the Jacchia 1977 model in program DENMOD. Previously these functions had been regarded as constant for the time segment of each tabular value (1 day for solar activity, 3 hrs for geomagnetic activity), jumping discontinuously at the beginning of each new time segment. The linear interpolation method more accurately reflects the processing used in the development of the Jacchia models.

Calculation of smoothed solar activity has been modified to decouple the variation in solar distance over the smoothing period, also as described in Section 1.1.2. The reason for this procedure is that the smoothed solar activity is supposed to represent the solar disk component (in contrast to the active-region component) of the solar radiation striking the Earth's surface on the day for which the smoothing is taken, vis., the mid-point of the smoothing period. Underlying this approach is the fact that the average (smoothing) of the daily index at a fixed point in space over a period of time is known to correlate with the disk component of the solar radiation reaching that point at the middle of this time period. The daily activity index is the 10.7cm flux measured at the Earth's surface, and therefore it varies inversely as the square of the the Sun-Earth distance R. Therefore each value must be

Model Number	CELEST	CADNIP/BADMEP
0	NWL	-------
1	Jacchia 1964	Jacchia 1964
2	1966 Supplements	1966 Supplements
3	Jacchia 1971	Jacchia 1971
4	U.S.S.R. - Cosmos	U.S.S.R. - Cosmos
5	Jacchia-Walker-Bruce	Jacchia-Walker-Bruce
6	Jacchia 1977	Jacchia 1977
7	Lockheed/NASA	Lockheed/NASA
8	MSIS	MSIS
9	1962 U.S. Standard	1962 U.S. Standard
10	-------	MSIS 78
11	-------	DENSEL
12	Jacchia 1970	Jacchia 1970
13	Jacchia 1973	Jacchia 1973
14	-------	Forbes-Garrett-Gillete Model B

Table 4. Density Models Available

multiplied by the daily R^2 value to obtain the flux at a fixed distance, 1 A.U. The resulting average is then divided by R^2 for the day in question to give the correct value at the Earth's surface for that day. If, for example, for the day in question the Earth is at aphelion, failure to implement this procedure would result in an overestimate of the disk component of the total solar flux striking the Earth's surface that day.

1.3.3 Results and Interpretation

Of the three statistical measures mentioned previously, mean absolute value error and standard deviation are generally accepted as the best criteria for comparison. The algebraic mean is used only to detect possible bias in the model for the selected sample. The results are partitioned into high and low geomagnetic activity bins to permit determination of which models are best under particular conditions (other variables can be partitioned if appropriate). Overall averages are then corrected for incorrect weighting with respect to geomagnetic activity or other variables.

1.4 Atmospheric Density Determination

In-situ measurement by accelerometers, mass spectrometers, and ion density gauges has replaced satellite orbit decay analysis as the primary means of measuring atmospheric density. These instruments provide time and spatial resolution unavailable from orbital decay analysis because of the inherent smoothing present in the latter. In addition mass spectrometers and ion gauges provide composition data. Nevertheless orbital decay methods should be useful for the following reasons:

1) Supplement to in-situ data base

2) Calibration for in-situ measurements by comparision of orbit-averaged or orbit-integrated densities

3) Diagnostic tool when in-situ data unavailable, for instance to determine relation of prediction errors to density variation

Density determinations have thus continued, using CELEST as described in Ref. 24 in conjunction with Doppler beacon data received from the Defense Mapping Agency (DMA).

1.4.1 Data File Conversion

Critical to the operation of CELEST is the proper creation of certain data files (TAPE14: preprocessed observations; TAPE19: master Sun-Moon/coordinate transformation tables) generated elsewhere. This data is sent from DMA in BCD format and must be converted to binary for use by CELEST. Formats for this data are given in Tables 5-8.

RECORD TYPE	WORD NUMBER	VARIABLE TYPE	VARIABLE NAME	FORMAT USED FOR ENCODING
1	1	A	WORD	A6
	2	I	SAT	I4
2	1	R	YEAR	F6.0
	2	R	DAY	F6.0
	3	D	TTCA	E20.14
	4	A	ISTA	A6
	5	I	ICLAS	I2
	6	I	ITYPE	I2
	7	D	OCTOL	E20.14
	8	I	NO	I3
	9	I	NBI	I3
	10	R	TEMPR	F5.0
	11	R	PRESS	F5.0
	12	R	HUM	F5.0
	13	I	ITI	I2
	14	I	IF	I2
	15	I	IP	I2
	16	I	IQPR	I6
3	1	D	XLAM	E20.14
	2	D	PHI	E20.14
	3	D	ALT	E20.14
	4	D	FS	E20.14
	5	R	DUMMY (1)	F10.0
	6	R	DUMMY (2)	F10.0
	7	R	DUMMY (3)	F10.0
	8	R	DUMMY (4)	F10.0
4	1	D	DA(I,1)	E19.13
	2	D	DA(I,2)	E19.13
	3	D	DA(I,3)	E12.6
	4	D	DA(I,4)	E10.4
	5	D	DA(I+1,1)	E19.13
	6	D	DA(I+1,2)	E19.13
	7	D	DA(I+1,3)	E12.6
	8	D	DA(I+1,4)	E10.4

Record type 4 is repeated until all data points are written (I=1,NO)
Record types 2, 3 and 4 are repeated for each data pass.
A description of each of the above variables is contained in Table 6.

Table 5. CELEST Time Corrected Observations: BCD Data File Description

Record Type	Word Number	Word Type	Quantity	Description
1	1	A	IOBC	"OBS FI"
	2	I	SAT	NWL Satellite No.
2	1	R	YEAR	Observation year
	2	R	DAY	Observation day
	3	R	TTCA	Predicted time of closest approach (sec from midnight)
	4	A	ISTA	Station number
	5	I	ICLAS	Data Class
	6	I	ITYPE	Data type
	7	R	OCTOL	O-C tolerance for filtering data
	8	I	NO	Number of obs.
	9	I	NBI	Unused (=0)
	10	R	TEMPR	Temperature
	11	R	PRESS	Pressure
	12	R	HUM	Humidity
	13	I	ITI	Unused (=0)
	14	I	IF	Unused (=0)
	15	I	IP	Unused (=0)
	16	I	IQPR	Q-number
	17	R	XLAM	Station longitude (Deg)
	18	R	PHI	Station latitude (Deg)
	19	R	ALT	Station altitude (km)
	20	R	FS	Satellite frequency
	21-24	R	DUMMY(1)-DUMMY(4)	Unused (=0)
3	1	R	DA(1,1)	Time of 1st obs.
	2	R	DA(1,2)	Observation value
	3	R	DA(1,3)	Sigma for obs.
	4	R	DA(1,4)	Tag (0=good obs)
	.	.	.	
	.	.	.	
	.	.	.	
	4*NO	R	DA(NO,4)	

1 type 1 record per file
1 type 2 record and 1 type 3
record per data pass

Table 6. CELEST Time Corrected Observations: Binary Data File

Record type	Format	#Words
1	3 E20.8	3
2	5 E18.8	20
3	5 E18.8	20

Record type 1 occurs once per year

Record type 2 ocurs once per day, 4 lines each

Record type 3 occurs once per year, following daily Record type 2 data for that year

Data described in Table 8

Table 7. CELEST Master Sun-Moon/Coordinate Transformations: BCD File Description

Record Type	Word Number	Word Type	Quantity	Description
1	1	R	RTYPE	Any positive number
	2	R	RYR	Year (last 2 digits)
	3	R	RDD	Number of days in the year
2	1	R	RTYPE	Any positive number
	2	R	DRDA	Day number (1 Jan = 1.0)
	3	R	XSUN	Rectangular coordinates
	4	R	YSUN	(km) of sun in 1950
	5	R	ZSUN	inertial reference system at midnight (GMT) of day
	6	R	XMOON 1	Rectangular coordinates
	7	R	YMOON 1	(km) of moon in 1950
	8	R	ZMOON 1	inertial ref. system at midnight (GMT) of day
	9	R	XMOON 2	Same as words 6-8,
	10	R	YMOON 2	except at noon
	11	R	ZMOON 2	
	12	R	DLSI	Nutation in longitude (radians)
	13	R	EP	Mean obliquity (radians)
	14	R	DELEP	Nutation in obliquity (radians)
	15	R	DLT	Seasonal correction to Earth's rotation (sec.)
	16	R	DLH	Equation of equinoxes (radians)
	17	R	P	Polar motion correction
	18	R	Q	parameters-added to 2nd and 1st parameters, respectively on RCC08 card; usually = 0
	19,20			Unused (=0)
3	1	R	RTYPE	Negative number, indicates this is last record of year
	2-20			Unused

Words 12-18, record type 2 are at midnight, GMT.

Table 8. CELEST Master Sun-Moon/Coordinate Transformation: Binary File Description

Programs DMABIN and BINAR perform the required conversion of the observation and Sun-Moon/transformation data, respectively, from the BCD to binary formats required by CELEST. The input tape in each case has the following specifications:

Logical file name: TAPE 1
Density: HI (556 BPI, 7-track)
Record Manager: RT=S, BT=C

The output tape in each case is TAPE 2. Program DMABIN requires the following input card:

Col	Variable	Format	Description
1-5	NFILE	I5	Number of files on input tape
6-10	IREW	I5	1=rewind at end of run 0=don't rewind

The observation input tapes generally contain 1-5 files (days) of data each, but conversion to binary and selection of higher density permit much more to be written on one output tape. Thus several runs of DBAMIN may be executed in one job, replacing input tapes between runs. Thus IREW should be 0 for all but the last run, when IREW should be 1 to prevent the system from attempting to read blank tape in subsequent use. The output tape would thus have an end-of-file after each file (day) of data and be terminated by proper end-of-information markers if rewound at end of last run.

Program BINAR requires no input other than the tape which usually contains two years of data. In practice the output can be catalogued as a permanent file on disk; thus rewind is not necessary.

1.4.2 Operational Procedures

Operation of CELEST is as described in Ref. 24 except that, as noted previously, observations received from DMA are already preprocessed. Thus execution of the

preprocessor module in CELEST is skipped. The data span (usually one day and the last 4 1/2 hrs of the previous day for overlap) can be divided into several drag segments. The Keplerian elements at the start of the fit span plus a drag coefficient for each drag segment are adjusted to perform a least-squares fit to the data. Density at perigee can be estimated as

$$D = (C_i/C_{TH})\, D_{model}$$

where

C_i = drag coefficient for the segment in which the perigee occurs

C_{TH} = theoretical drag coefficient (=2.2)

D_{model} = Density at perigee for the selected model

1.4.3 Rapid Density Variations

Very short drag segment durations are desirable to obtain the time resolution required to study the rapid variations which occur during magnetic storms. However, tracking data distribution in time and geopotential modelling errors place limits on the time resolution which can be obtained. The distribution and number of station passes in one revolution are highly variable, introducing much noise to the results if such short segments are used. Geopotential modelling errors begin to be absorbed significantly into the drag coefficient determined by least squares for segments smaller than four revs, although this effect may still be dominated by real drag variations if the latter are sufficiently large. Thus two revolutions appears to be the best possible time resolution that can be attained. Density variations, however, may occur on a much smaller time scale during high geomagnetic activity, because of the very sharp latitudinal dependence which may occur. Therefore perigee density, as defined above, is not a reliable or meaningful quantity. The most meaningful result is, rather, a suitable average of drag or density over the duration of the drag segment.

For this reason, CELEST has been augmented with the capability to integrate numerically the drag acceleration magnitude over a segment to obtain the average drag over a segment by:

$$\bar{g}_D = C_D \int_{t_0}^{t_1} g_D\,(t)\, dt/(t_1 - t_0)$$

where

C_D = drag coefficient determined for the segment

t_o = start time of segment

t_1 = end time of segment

$g_D(t) = ADV^2/2M$

$\frac{A}{M}$ = satellite area to mass ratio

D = atmospheric density according to chosen model

V = satellite velocity

The function $g_D(t)$ is integrated using the Gauss - Jackson formulation discussed in Reference 22, expanding the 3 dimensional position vector x being solved for to a 4 dimensional vector:

$$\ddot{X} = G\ (x, \dot{x}, t)$$

where the first three components of x are the original Cartesian position components and the fourth component corresponds to the drag:

$$G_4 = g_D$$

Thus $\dot{X}_4$ is the result of interest. Initial conditions are

$$X_4 = \dot{X}_4 = 0.$$

The average acceleration over a drag segment is then:

$$\bar{a}_D = [\dot{X}_4(t_1) - \dot{X}_4\ (t_o)]/(t_1 - t_o)$$

The orbit generation module of CELEST was upgraded to perform this expanded computation.

The average drag predicted by the chosen model is computed for comparison (Figures 4 and 5) simply by setting C_D to a fixed value. These results clearly indicate a greater response of the model to geomagnetic activity increases for the particular active period shown than the actual atmospheric response as deduced from the tracking data.

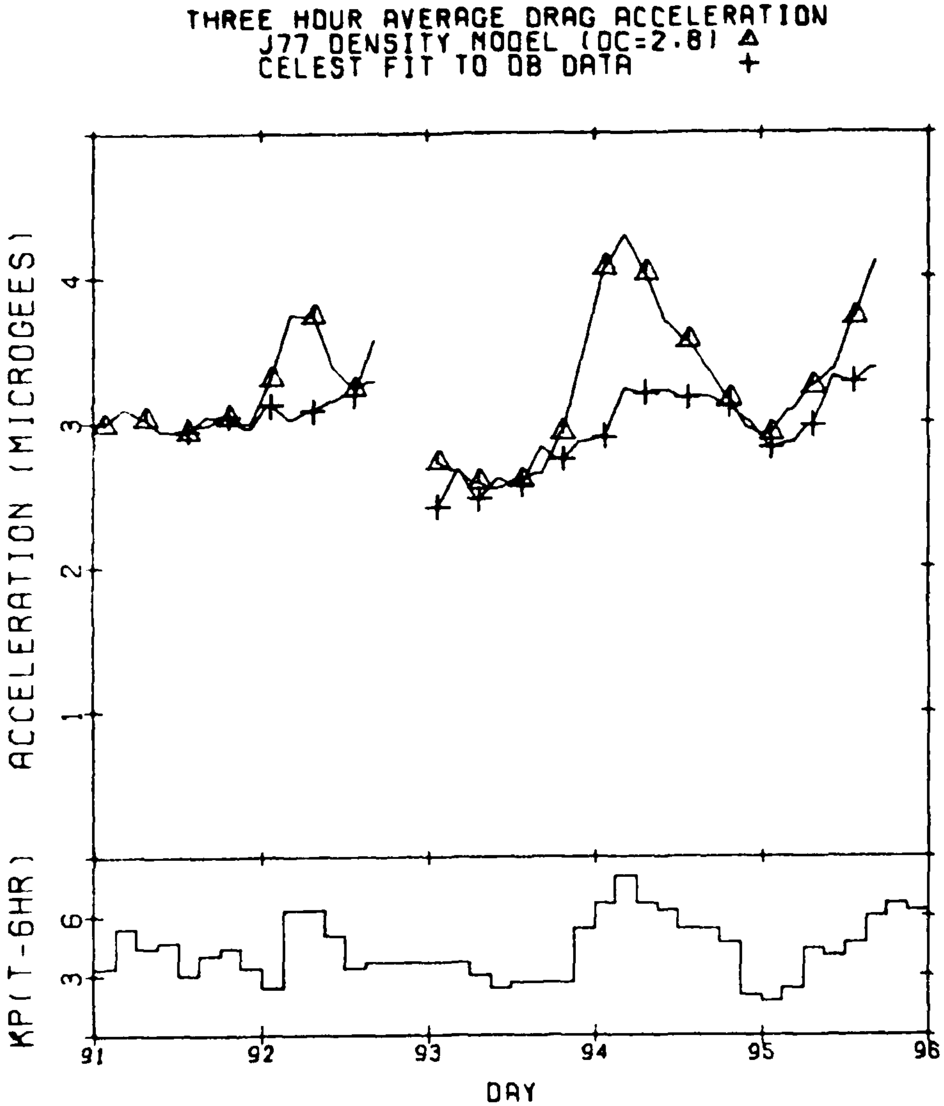

Figure 4. Comparison of 3 Hour Averaged Drag Acceleration predicted by J77 Density Model (Triangles) with that deduced from Satellite Tracking Data (Crosses) for period of High Geomagnetic Activity

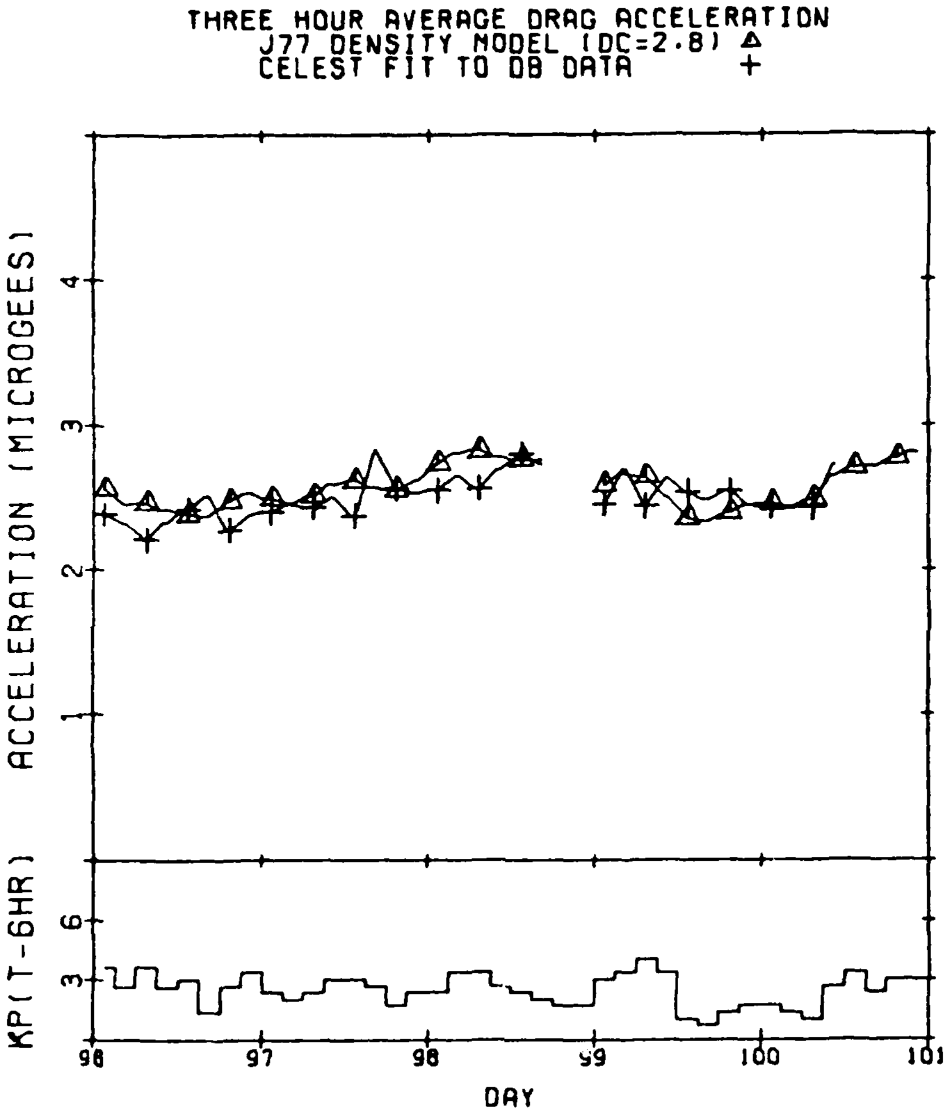

Figure 5. Same as Figure 4, except for Subsequent Geomagnetically Quieter Period.

1.5 References

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2.0 Satellite Ephemerides

Critical to the use of satellites for geophysical measurement and exploration tasks is the need to have knowledge of vehicle position as a function of time. In some applications, the requirements for accuracy can be very exacting. In general terms, the problem involves some combination of smoothing, interpolating and extrapolating radar observations. This section is devoted to discussion of LOKANGL, a program that has proven of great usefulness in furnishing orbital information to support a variety of satellite projects. A system of coordinates, known as solar/magnetospheric, has been found useful in the study of solar interactions with the magnetosphere. In support of the SCATHA effort, the capability has been added to Program LOKANGL to express satellite ephemerides in this system and to plot the results.

2.1 LOKANGL

2.1.1 Introduction

Program LOKANGL is a utility program for general calculations of satellite ephemerides. It has assumed this role with the general availability of high quality orbital elements, which form the major input to the calculations.

The origins of LOKANGL can be traced to an orbit and ephemeris programs, called DABOS, developed by Minka, Fein, and Clemenz [1]. The major thrust of DABOS was the application of minimum variance filtering techniques to raw radar observations. This task is currently performed by the agencies which furnish the orbital element sets which are used as input to LOKANGL.

Although LOKANGL avoids filtering raw data in favor of a more computationally efficient technique, much of its structure has been taken from the earlier program. Thus Reference 1 has considerable material of relevance to LOKANGL. Evolving by stages, LOKANGL consists of software modules of various origins which have been added as special needs arose. However, the basic program has now remained static for several years. Special purpose versions continue

to be developed (see sections 3.0 and 4.0), but such modifications have not been made a part of the basic LOKANGL system. It is appropriate at this stage, then, to discuss LOKANGL, both to document the up-to-date version of the basic program and to form the basis for presenting more recent programs for which LOKANGL forms the foundation.

The basic objective of LOKANGL is efficient (in terms of central processor time) calculation of satellite ephemerides. The method used is to extrapolate mean orbital elements by means of power series expansions. The limited range of applicability of such expansions translates into a definite restriction on the extent of the time interval over which valid predictions can be made. Nevertheless, when element sets are available for epochs sufficiently close to the times of interest, LOKANGL provides reliable results for a much lower investment in computing time than routines that require solution of the governing differential equations.

LOKANGL can be furnished one or more sets of orbital elements. It obtains the derivatives of the mean elements, needed for calculation, in one of several ways. First consider the case in which only one element set is furnished. If the derivatives ,in addition to elements, are supplied by the issuing agency, these values are used. Otherwise, the time derivatives of the elements are calculated based upon internal physical models for the Earth's atmospheric density and geopotential. Calculation of derivatives based on these models follows procedures presented by King-Hele [(2)]. The given elements, together with their calculated derivatives, are then used to perform extrapolations either backward or forward in time. Extrapolated mean elements are then converted to equivalent alternative forms, as required by the application. However, when given two or more element sets, and ephemeris data is required at a time that is intermediate to the epochs of two of these element sets, LOKANGL makes explicit use of the inherent time-variation between these two successive sets to evaluate derivatives during the intervening period. This feature overrides the internal methods of calculating derivatives which are used in the absence of spanning elements. Any number of consecutive (i.e., time-ordered) element sets can be furnished to the program . They are used pairwise to evaluate time derivatives to be used within the time interval spanned between their respective epochs.

Satellite ephemerides can be output in a variety of forms. In addition, various related quantities can also be computed. These include: station look angles (i.e., topocentric coordinates of satellite) for both fixed and moving (e.g., an aircraft) stations; coordinates of intersection of station-satellite line-of-sight with the ionosphere; angle between satellite-sun line and satellite's Earth horizon (defines eclipse conditions).

Table 1 summarizes major features of the program.

- Can use pairs of element sets to compute time variation of elements
- Has internal atmospheric density/drag and geopotential models for evaluating time derivatives of elements based on method of King-Hele
- Accepts variety of types of orbital elements
- Provides look angles to satellite for both fixed and moving (i.e., aircraft) stations
- Provides ionospheric intersections for satellite-station paths
- Indicates solar illumination/shadowing of satellite
- Provides option for standard output ephemeris file and/or several types of plot files
- Provides option for printing variety of output listings

Table 1. Major Features of LOKANGL

2.1.2 Approach and Program Organization

Figure 1 illustrates the flow of information and key operations in LOKANGL. Table 2 exhibits the roles of key routines. Any one of five different standard types of element sets can be input. (The type of elements furnished varies among the agencies that supply them). Element derivatives are obtained differently for the different types of sets, as shown in Figure 1. The internal atmospheric density/drag model and geopotential model provide data which is needed to perform transformations between types of elements and to evaluate element derivatives. The interpolation method of evaluating derivatives is employed wherever spanning element sets are available. Propagation of elements from their epoch to the time of interest is performed in terms of mean elements. These mean elements are then converted to osculating elements for calculations of instantaneous values of observable parameters such as position and velocity. Ancillary calculations include: solar ephemeris; Greenwich sidereal time; ECI to topocentric coordinate transformations; and solution for station-satellite line-of-sight intersection with the ionosphere.

2.1.3 Input

Input to LOKANGL is by means of punched cards. Their layout and organization are shown in Table 3. Note that five different types of element sets can be accommodated. Organizations which furnish elements include the following:

NORAD (mean Keplerian elements)
SCF (position/velocity vectors)
NASA (Brouwer mean Keplerian elements
and osculating Keplerian elements)
COMSAT (mean Keplerian elements).

Figures 2 to 5 illustrate the format of cards for different element types.

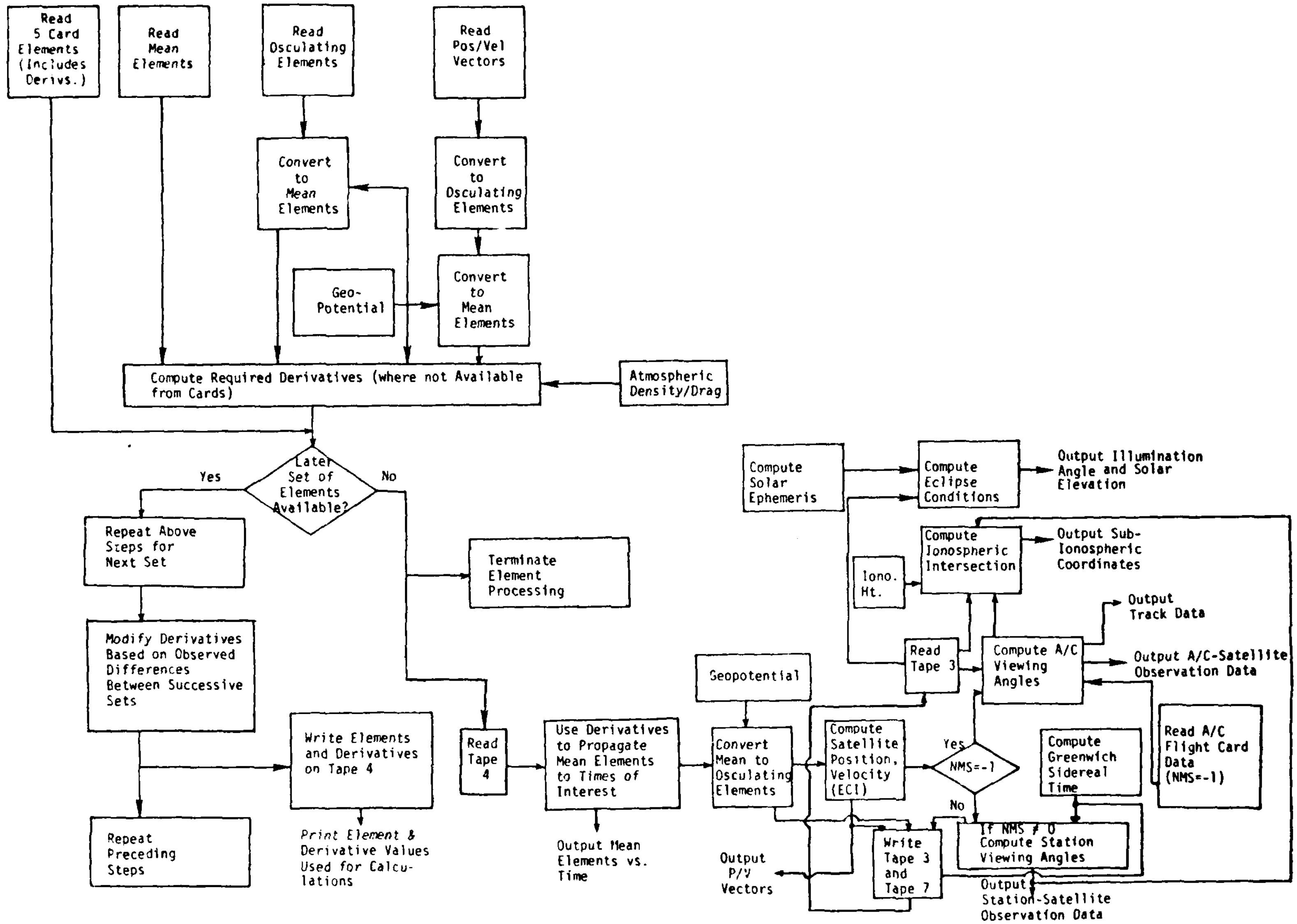


Figure 1. Simplified Operational and Data Flow for LOKANGL

o LOKANGL (Main Program)

Reads input cards (except flight cards)

Depending on type of element set, calls appropriate routine to convert to mean elements and evaluate derivatives.

If second element set is given, interpolates derivatives over spanning interval

Computes elements at times of interest

Calls FLTRANS to read flight cards

Calls SPPROU to perform ephemeris calculations at each time of interest

Calls WRSTP to perform solar/ionosphere/aircraft (moving station) related calculations

Clocks operation in incremental steps from initial to final time

Terminates job when final time is reached.

o SPPROU (Ephemeris Routine)

Called for each type of calcuation

Calculates ephemeris quantities

Writes ephemeris on file TAPE3

Writes perigee-apogee data on file TAPE7

Converts mean elements to osculating values and to P/V vectors

Determines station viewing parameters

Evaluates Greenwich sidereal time

Prints variety of types of ephemeris output.

o WRSTP (Moving Station Routine)

Called only once

Reads TAPE3 to obtain ephemeris data

Calls CORFL for interpolated A/C coordinates

Calls SOLVIL to evaluate solar illumination conditions

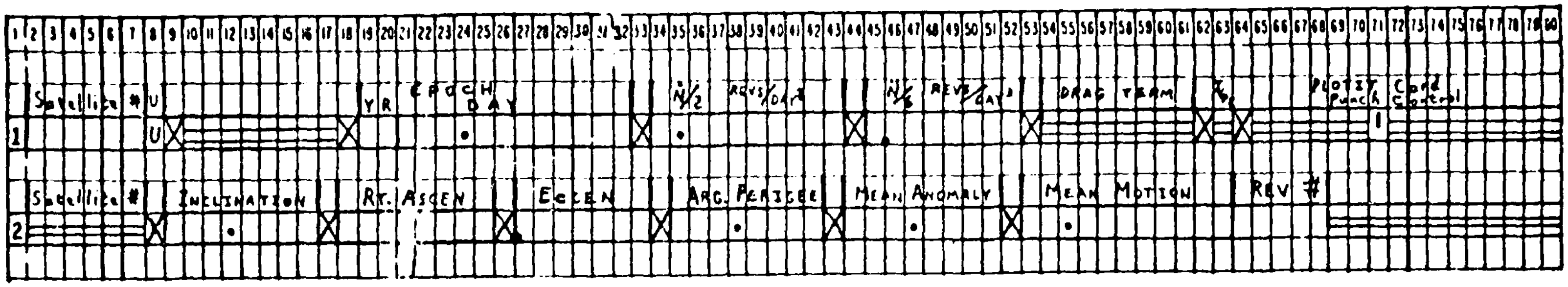
Calls SILL2 to determine station-satellite line-of-sight intersection with ionosphere

Prints output for moving station, inospheric intersection, and satellite eclipsing calculations.

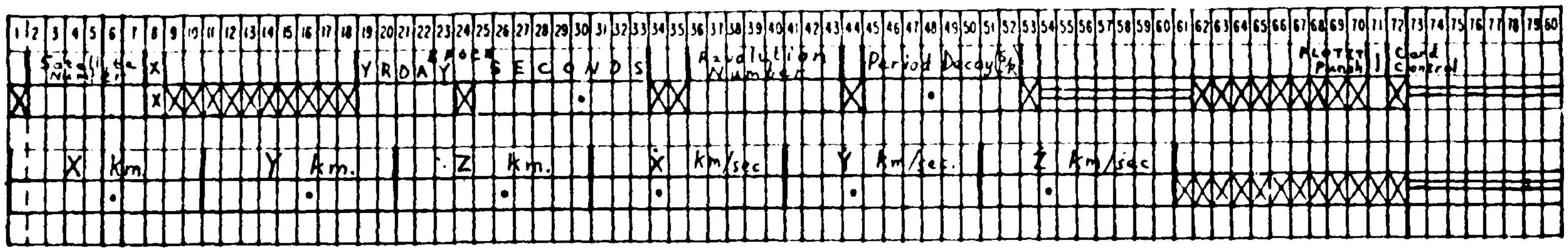
Table 2. Major Routines and Their Chief Functions

```
************************************************************
--INPUT FORMAT FOR PROGRAM LOKANGL
************************************************************
- DATA DECK SETUP

 CARD    COLS              DESCRIPTION
 1       1      CODE OF ORBITAL DETERMINATION FORM
                1=FORM NO. 3 \   SCF 2-CARD POS.-VEL. SET
                2=FORM NO. 2 \   ADC 2-CARD ELEMENT DATA SET
                3=3-CARD ELEMENT DATA SET
                4=OSCULATING ELEMENTS
                5=FORM NO. 1\ ADC 5-CARD DATA SET

 2*             ONE OR MORE ELEMENT SETS
         8-9    X OR U ON FIRST CARD OF ALL SUBSEQUENT ELEMENT SETS
         8      T INDICATES THRUST TIME CARD\ ONE CARD SET
                PROVIDES TIME OF THRUST IN STANDARD COLUMNS

 3       1-3    NO. OF STATIONS. IF NO STATIONS USE 0
                FOR AIRCRAFT FLIGHT SIMULATION RUN, USE -1
         6      CODE 1 OR 0 FOR PRINT CONTROL OF STATION DATA
                0=PRINT BY TIME ONLY
                1=PRINT BY STATIONS
         7-10   0=STANDARD
                IONOHT=SUB-IONOSPHERIC ALTITUDE (KM)     I3
         13-15  MINELV= MIN ELEVATION FOR SAT VIEWING   I3
         16-30  FOR AIRCRAFT FLIGHT SIMULATION RUN, ALTITUDE OF
                AIRCRAFT (M) F15.1

 3*             STATION LOCATION CARDS,IF NMS.GT.0
         1-5    I.D. OF STATION (NUMBER)
         7-8      2=GEODETIC SYSTEM
         9-23   STATION GEODETIC LATITUDE. DEGREES
         24-38  STATION LONGITUDE (POSITIVE WEST). DEGREES
         39-53  STATION HEIGHT. METERS
         61-72  NAME OF STATION

 4       1-15   TIME INCREMENT IN SECONDS. F15.5
         17-69  TIME INTERVAL FOR PRINT OR TAPE 3 WRITE
                START COLS\ 17-18;20-21;23-24;26-29;31-34;36-41
                FINAL COLS\ 43-44;46-47;49-50;52-55;57-60;62-67
                TIME        MONTH;  DAY; YEAR; HOUR;  MIN;  SEC
                FORMAT         I2;   I2;   I2; F3.1; F3.1; F5.3
                FINAL TIME NOT NECESSARY IF NMS.EQ.-1

 5              AIRCRAFT POSITION-TIME CARDS, IF NMS.EQ.-1
 5A             TITLE REQUIRED (4A10)
  3*            TWO OR MORE POSITION-TIME CARDS
         1-5    HOURS FROM STARTING TIME I5
         6-10   MINUTES F5.0
         11-15  DEGREES LATITUDE I5
         16-20  MINUTES LATITUDE  I5
         21-25  DEGREES LONGITUDE I5
         25-30  MINUTES LONGITUDE I5
  Z      2-5    "1000" INDICATES END OF POSITION-TIME CARDS

 6              CODE FOR PRINT-OUT  0= NO PRINT; 1= PRINT FOLLOWING
         2      1=POSITION AND VELOCITY
         4      1=SUB-SATELLITE DATA
         6      1=MEAN ELEMENTS
         8      1=OBSERVATION DATA
         9-10   0=STANDARD BINARY ON TAPE3
                -1=PERIGEE-APOGEE DATA ON TAPE7
         11-13  1.0=SINGLE PASS REFRAC. CORRECTION (STANDARD)
 7              "END OF PROBLEM"

 ABOVE MAY BE REPEATED N TIMES
 LAST CARD\ "9" IN COL. 1
************************************************************
```

Table 3. Input Format for Program LOKANGL



NORAD SPADATS 2-Card Element Set



SCF Position/Velocity Vectors

Figure 2. NORAD SPADATS Element Set and SCF Position/Velocity Vectors

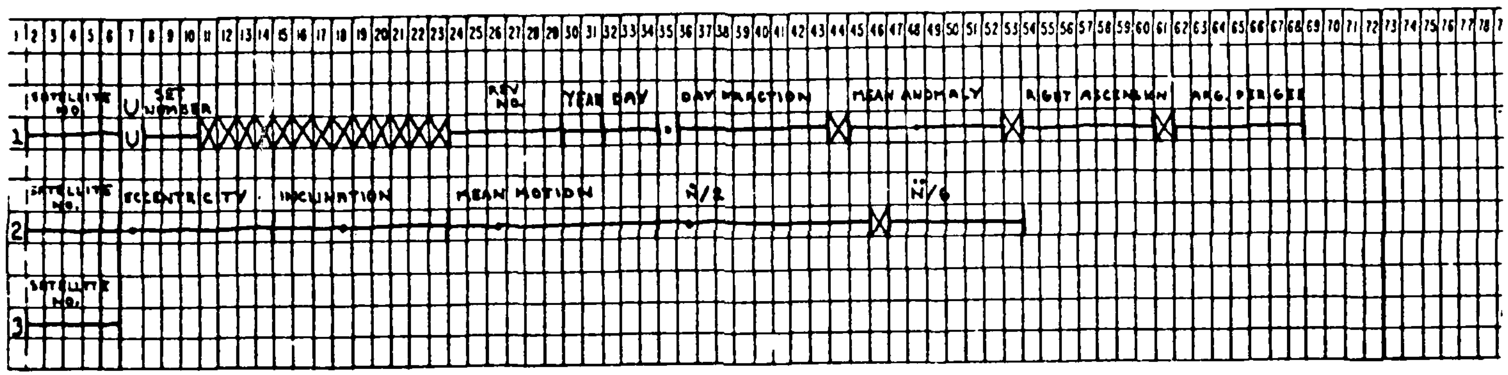


Figure 3. NORAD 3-Card Element Set

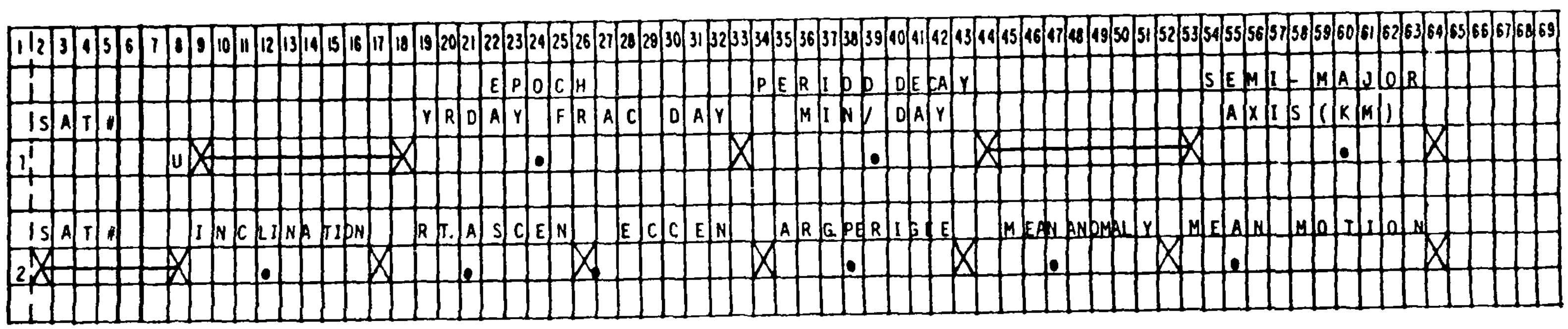


Figure 4. NASA 2-Card Osculating Element Set Format

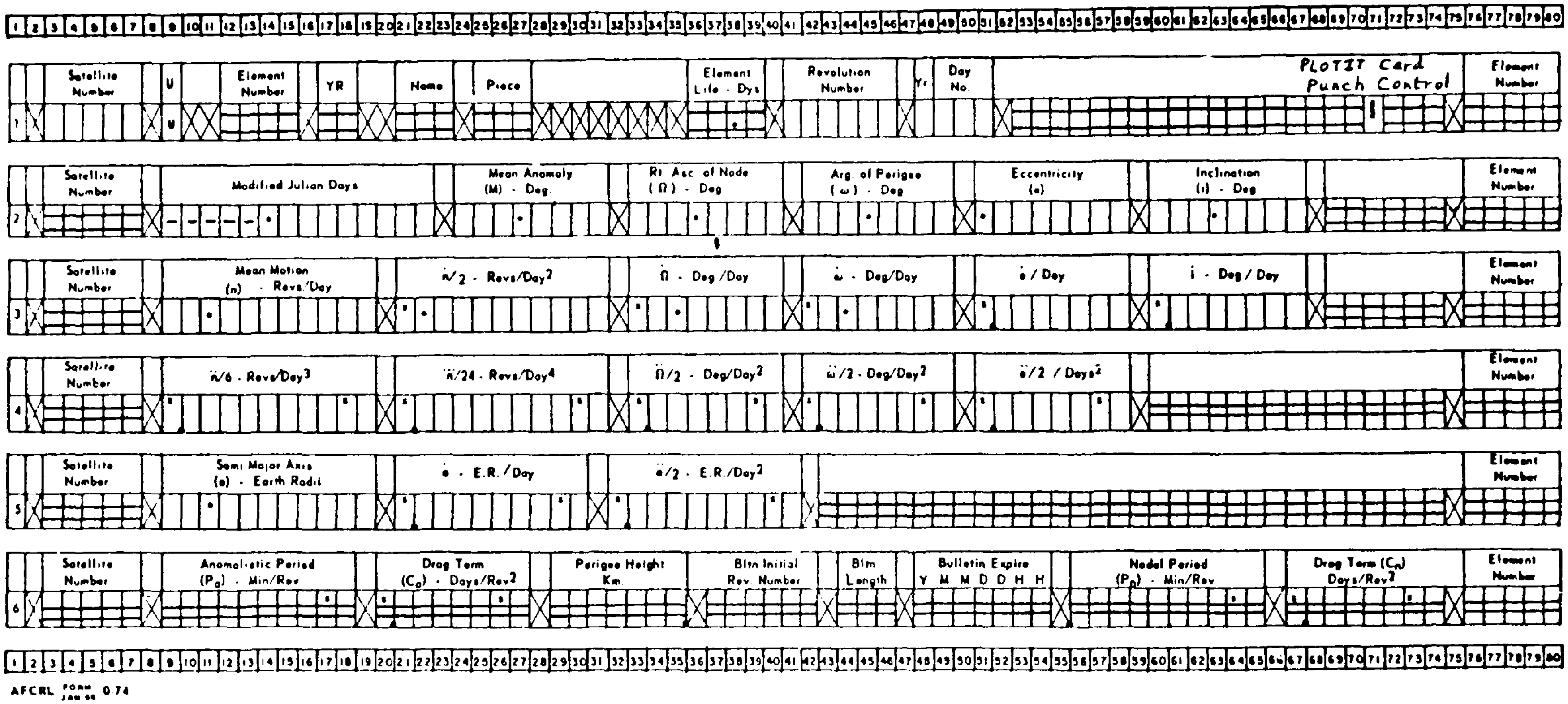


Figure 5. NORAD 5-Card Element set Format

Thrust cards are a special class of element card which signal the occurrence of an orbit adjust at specified times. The hallmark of thrust cards is the 1 in column 8. Other thrust information on the card is:

- o Columns 19-20, year in format I2;
- o Columns 21-23, day number in format I2;
- o Columns 24-33, time in seconds in format F10.3.

A thrust card should be both preceded and followed by standard element cards.

LOKANGL interprets the occurrence of a thrust as a discontinuity in the orbit. The program divides the interval between the epochs of the element sets occurring immediately before and after a thrust card into two intervals:

interval #1 - from epoch of preceding set up to thrust time;

interval #2 - from thrust time up to epoch of following set.

In the first interval the program performs a forward extrapolation; in the second, a backward extrapolation. Thus, during both interval 1 and 2, it is not possible to obtain derivatives by the process of interpolating between spanning element sets.

2.1.4 Printed Output

Eight standard types of listed output are available, seven of which are selectable by choice of options on the input cards. The eighth is a standard header which precedes all listed output. These output types are summarized below, and examples are presented in Figures 6 to 12.

1) Header (common to all output print options) Figure 6

Type of elements used, epoch
Element values and derivatives
Initial and final print times; time increment
Print option selected
Initial orbital parameters

2) Sub-satellite position option (0,1,0,0 option) Figure 7

Date, time, rev number
Geocentric and geodetic latitude, W. longitude, altitude
Geocentric radius, velocity, local time

3) Mean elements option (0,0,1,0 option) Figure 8

Date, time
Semi-major axis, eccentricity, inclination
Ascending node, argument of perigee, mean anomaly

4) Position/Velocity option (1,0,0,0 option) Figure 9

Date, time
X, Y, Z, VX, VY, VZ

5) Station observation option (0,0,0,1 option) Figure 10

Date, time (including seconds of day)
Rev number, elevation, azimuth
Range, right ascension, declination
Time derivatives of: elevation, azimuth,
range, declination, right ascension

6) Aircraft flight/ionosphere option (NMS=-1) Figure 11

Flight segment, date, time
Aircraft latitude and longitude
Aircraft to satellite viewing parameters:
elevation, azimuth, range, range rate
Sub-ionospheric point: latitude, longitude
Sub-satellite point: latitude, longitude

7a) Station look angles/sub-satellite point/satellite occultation option (default option: columns 2, 4, 6, and 8 of card 6 are all zero; NMS$\geq$1; and ionospheric height omitted on card 3) — Figure 12a

Station number, date, time

Station viewing parameters: elevation, azimuth, slant range, right ascension, declination, altitude

Sub-satellite point: latitude, longtitude, solar elevation

Illumination (eclipse) angle (angle between satellite - Sun line and satellite's Earth horizon.)

Rev number

7b) Station look angles/sub-satellite point/satellite occultation/ sub-ionospheric point option (default option: columns 2, 4, 6, and 8 of card 6 are all zero; NMS$\geq$1; and non-zero ionospheric height is entered on card 3) — Figure 12b

Station number, date, time

Station viewing parameters: elevation, azimuth, slant range, altitude

Sub-ionospheric point: latitude, longtitude

Sub-satellite point: latitude, longtitude, solar elevation

Illumination (eclipse) angle (angle between satellite - Sun line and satellite's Earth horizon.)

Rev number

```
EPHEMERIS EXTRAPOLATION PROGRAM FOR SATELLITE   7802

DATE OF ELEMENTS USED IN COMPUTATION - YEAR   DAY   HR MN SECS   REV. NO.
                                        1978    33    0  0   .0      51

 XPOS,KMS    YPOS,KMS   ZPOS,KMS     X,VEL,KMS  Y,VEL,KMS  Z,VEL,KMS  PER,DECAY
-12779.3200-47042.5890 -17[illegible].3135   2.[illegible]   -.[illegible]    .330135    0.0000

CONVERTED TO MEAN ELEMENTS BELOW

                       INITIAL VALUE                       FIRST TIME DERIVATIVE              SECOND TIME DERIVATIVE
INCLINATION            .[illegible]E+01 (DEGREES)          0.                 (DEGS/DAY)
ECCENTRICITY           .[illegible]E+00                    0.                 ( /DAY)         0.     ( /DAY**2)
SEMI MAJOR AXIS        .[illegible]E+01 (EARTH RADII)      0.                 (E.R./DAY)      0.     (E.R./DAY**2)
ARGUMENT OF PERIGEE    .[illegible]E+03 (DEGREES)          .290340[illegible]E-01 (DEGS/DAY)  0.     (DEGS/DAY**2)
R.A. OF ASC. NODE      .[illegible]E+03 (DEGREES)          -.147500[illegible]E-01 (DEGS/DAY) 0.     (DEGS/DAY**2)
MEAN MOTION            .[illegible]E+01 (REVS/DAY)         0.                 (REVS/DAY**2)   0.     (REVS/DAY**3)
THIRD TIME DERIVATIVE OF MEAN MOTION = 0.                  (REVS/DAY**4)      MEAN ANOMALY =  .14870739E+03 (DEGREES)

FIRST TIME DERIVATIVES OF  I, E, A, W, N, MF   HAVE BEEN ADJUSTED TO
     .325[illegible]E-02   -.2[illegible]E-04   -.[illegible]E-04   .[illegible]E-01   -.1535013E-01   .1011[illegible]2E+01


EPHEMERIS EXTRAPOLATION PROGRAM FOR SATELLITE   7802

DATE OF ELEMENTS USED IN COMPUTATION - YEAR   DAY   HR MN SECS   REV. NO.
                                        1978    30    0  0   .0      53

 XPOS,KMS    YPOS,KMS   ZPOS,KMS     X,VEL,KMS  Y,VEL,KMS  Z,VEL,KMS  PER,DECAY
12261.7604-47913.1370  1[illegible]    2.[illegible]      .[illegible]    .[illegible]    0.0000

CONVERTED TO MEAN ELEMENTS BELOW

                       INITIAL VALUE                       FIRST TIME DERIVATIVE              SECOND TIME DERIVATIVE
INCLINATION            .[illegible]E+01 (DEGREES)          0.                 (DEGS/DAY)
ECCENTRICITY           .[illegible]E+00                    0.                 ( /DAY)         0.     ( /DAY**2)
SEMI MAJOR AXIS        .[illegible]E+01 (EARTH RADII)      0.                 (E.R./DAY)      0.     (E.R./DAY**2)
ARGUMENT OF PERIGEE    .[illegible]E+03 (DEGREES)          .29097[illegible]E-01 (DEGS/DAY)   0.     (DEGS/DAY**2)
R.A. OF ASC. NODE      .[illegible]E+03 (DEGREES)          -.1474[illegible]E-01 (DEGS/DAY)   0.     (DEGS/DAY**2)
MEAN MOTION            .[illegible]E+01 (REVS/DAY)         0.                 (REVS/DAY**2)   0.     (REVS/DAY**3)
THIRD TIME DERIVATIVE OF MEAN MOTION = 0.                  (REVS/DAY**4)      MEAN ANOMALY =  .19110209E+03 (DEGREES)

STATION DATA (NOTE-PROGRAM DEFINES NCC TO BE =2, HENCE LOOK ANGLES WILL BE MEASURED IN GEODETIC SYSTEM

  NUMBER     NAME          NCC   GEOD LAT. (DEG)   GEOC LAT. (DEG)   WEST LON. (DEG)   ALTITUDE (KM)    RADIUS (KM)
    31       COOK           2    .[illegible]E+02     .3[illegible]E+02     .30051300E+03    .[illegible]7113000E+00   .637210[illegible]2E+04

STATION PRINTOUT REQUESTED BY TIME ONLY WITH STANDARD OUTPUT

MINIMUM ELEVATION FOR SATELLITE VISIBILITY  [illegible] DEG.

EPHEMERIS PRINTOUT DATA

                        MONTH  DAY  YEAR      HR.  MIN.  SEC.
         START PRINT TIME   3    21    7[illegible]       0.   0.   0.000
         END PRINT TIME     3    26    7[illegible]       0.   0.   0.000

         PRINT EVERY  .[illegible]E+0[illegible](SECONDS)

PRINTOUT REQUESTED    1=YES    0=NO

POSITION-VELOCITY VECTOR =0    SUB-SATELLITE POSITION =0    ORBITAL ELEMENTS =0    STATION DATA =0
```

Figure 6. Sample Header for Normal Printout (NMS≠-1)

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PREPARED BY/FOR THE ANALYSIS AND SIMULATION BRANCH (SUA), AIR FORCE GEOPHYSICS LABORATORY, TELEPHONE 861-4161

EPHEMERIS EXTRAPOLATION PROGRAM FOR SATELLITE NUMBER 10620 PAGE 10

DATE MO	DY	YR	U TIME HR	MN	SEC	REV	GEOC LAT	GEOD LAT	WEST LONG	ALT(KM)	RADIUS(KM)	VEL(KM/SEC)	LOCAL TIME(HRS)
5	9	79	0	0	.000	5278	34.173	34.331	74.612	830.968	7202.364	7.4393	19.066
5	9	79	0	3	.000	5278	23.643	23.766	77.481	831.993	7206.705	7.4363	18.885
5	9	79	0	6	.000	5278	13.116	13.192	80.026	830.065	7207.144	7.4365	18.765
5	9	79	0	9	.000	5278	2.585	2.602	82.421	831.533	7209.654	7.4347	18.655
5	9	79	0	12	.000	5278	[illegible]	-8.061	84.793	831.317	7209.065	7.4352	18.547
5	9	79	0	15	.000	5278	[illegible]	-18.506	87.242	829.743	7204.793	7.4369	18.434
5	9	79	0	18	.000	5278	-28.947	-29.192	89.929	831.343	7204.453	7.4379	18.304
5	9	79	0	21	.000	5278	-39.001	-39.666	93.053	832.251	7201.739	7.4391	18.146
5	9	79	0	24	.000	5278	[illegible]	-50.083	97.022	835.091	7201.713	7.4374	17.931
5	9	79	0	27	.000	5278	[illegible]	-60.206	102.703	827.929	7190.016	7.4479	17.603
5	9	79	0	30	.000	5278	[illegible]	[illegible]	112.931	841.967	7201.238	7.4351	16.973
5	9	79	0	33	.000	[illegible]	[illegible]	-78.730	130.465	841.634	7193.240	7.4364	15.316
5	9	79	0	36	.000	5278	[illegible]	[illegible]	[illegible]	[illegible]	7187.467	7.4464	11.2??
5	9	79	0	39	.000	[illegible]	-73.773	[illegible]	[illegible]	834.067	7192.312	7.4437	8.74?
5	9	79	0	42	.000	5278	-64.141	-64.274	252.690	837.347	7191.753	7.4455	7.854
5	9	79	0	45	.000	[illegible]	[illegible]	-54.105	259.701	831.660	7196.027	7.4427	[illegible]
5	9	79	0	48	.000	[illegible]	[illegible]	-43.732	254.211	833.310	[illegible]	7.4389	[illegible]
5	9	79	0	51	.000	[illegible]	[illegible]	[illegible]	257.564	833.013	[illegible]	[illegible]	[illegible]
5	9	79	0	54	.000	[illegible]	[illegible]	-22.756	271.413	827.782	7202.766	[illegible]	6.872
5	9	79	0	57	.000	[illegible]	[illegible]	-12.102	272.937	831.013	7203.236	7.4356	[illegible]
5	9	79	1	0	.000	[illegible]	[illegible]	-1.562	275.329	829.413	[illegible]	7.4369	[illegible]
5	9	79	1	3	.000	[illegible]	[illegible]	8.051	[illegible]	831.701	7219.341	[illegible]	[illegible]
5	9	79	1	6	.000	[illegible]	[illegible]	19.027	[illegible]	828.571	7224.338	[illegible]	[illegible]
5	9	79	1	9	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	9	79	1	12	.000	5279	[illegible]	[illegible]	236.072	837.603	7202.721	[illegible]	[illegible]
5	9	79	1	15	.000	[illegible]	[illegible]	51.091	230.164	837.573	7202.632	7.4361	5.906
5	9	79	1	18	.000	[illegible]	[illegible]	61.351	236.219	824.654	[illegible]	[illegible]	[illegible]
5	9	79	1	21	.000	5279	[illegible]	71.136	311.214	842.620	[illegible]	7.4363	[illegible]
5	9	79	1	24	.000	5279	[illegible]	79.221	334.499	840.633	7190.165	7.4375	[illegible]
5	9	79	1	27	.000	5279	[illegible]	80.420	[illegible]	823.763	[illegible]	[illegible]	22.907
5	9	79	1	30	.000	5279	[illegible]	72.916	73.446	840.171	7198.811	7.4373	20.604
5	9	79	1	33	.000	5279	63.137	63.274	86.253	836.430	7197.562	7.4397	19.799
5	9	79	1	36	.000	5279	[illegible]	[illegible]	92.564	[illegible]	7195.775	7.4471	[illegible]
5	9	79	1	39	.000	5279	[illegible]	42.739	97.243	830.371	7196.724	7.4417	[illegible]
5	9	79	1	42	.000	5279	[illegible]	32.294	100.557	829.164	7201.255	[illegible]	[illegible]
5	9	79	1	45	.000	5279	21.671	[illegible]	113.343	831.465	7206.693	[illegible]	[illegible]
5	9	79	1	48	.000	5279	[illegible]	11.152	105.651	830.407	[illegible]	7.4383	[illegible]
5	9	79	1	51	.000	5279	[illegible]	.554	108.233	831.989	7210.152	7.4342	[illegible]
5	9	79	1	54	.000	5279	[illegible]	-10.109	110.613	829.661	7207.192	7.4370	[illegible]
5	9	79	1	57	.000	5279	[illegible]	[illegible]	[illegible]	831.722	[illegible]	[illegible]	[illegible]
5	9	79	2	0	.000	5279	[illegible]	-31.214	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	9	79	2	3	.000	5279	[illegible]	[illegible]	[illegible]	832.950	[illegible]	[illegible]	[illegible]
5	9	79	2	6	.000	5279	[illegible]	[illegible]	123.295	[illegible]	[illegible]	[illegible]	[illegible]
5	9	79	2	9	.000	5279	[illegible]	-62.226	[illegible]	824.259	[illegible]	7.4521	17.511
5	9	79	2	12	.000	5279	[illegible]	[illegible]	[illegible]	834.722	7193.597	[illegible]	16.791
5	9	79	2	15	.000	5279	[illegible]	[illegible]	[illegible]	840.250	[illegible]	[illegible]	[illegible]
5	9	79	2	18	.000	5279	-79.777	[illegible]	237.147	[illegible]	7193.335	7.4424	[illegible]
5	9	79	2	21	.000	5279	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.4446	[illegible]
5	9	79	2	24	.000	5279	[illegible]	[illegible]	[illegible]	832.112	[illegible]	[illegible]	[illegible]
5	9	79	2	27	.000	5279	[illegible]	[illegible]	[illegible]	831.354	7196.229	[illegible]	[illegible]
5	9	79	2	30	.000	5279	[illegible]	[illegible]	[illegible]	[illegible]	7199.739	[illegible]	[illegible]
5	9	79	2	33	.000	5279	[illegible]	[illegible]	[illegible]	834.059	[illegible]	[illegible]	[illegible]
5	9	79	2	36	.000	5279	[illegible]	[illegible]	[illegible]	[illegible]	7204.033	7.4354	[illegible]
5	9	79	2	39	.000	5279	[illegible]	[illegible]	[illegible]	830.735	[illegible]	[illegible]	[illegible]
5	9	79	2	42	.000	[illegible]	[illegible]	.497	[illegible]	[illegible]	7207.551	[illegible]	[illegible]
5	9	79	2	45	.000	[illegible]	[illegible]	11.073	[illegible]	831.936	[illegible]	[illegible]	[illegible]
5	9	79	2	48	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7204.407	[illegible]	[illegible]
5	9	79	2	51	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7202.771	[illegible]	[illegible]
5	9	79	2	54	.000	[illegible]	[illegible]	[illegible]	312.125	834.434	7202.802	7.4375	[illegible]
5	9	79	2	57	.000	[illegible]	[illegible]	53.112	310.454	837.110	7201.631	7.4370	[illegible]

Figure 7. Sample Sub-Satellite Printout

PREPARED BY/FOR THE ANALYSIS AND SIMULATION BRANCH (SUA), AIR FORCE GEOPHYSICS LABORATORY, TELEPHONE 861-4161

EPHEMERIS EXTRAPOLATION PROGRAM FOR SATELLITE NUMBER 10820 PAGE 3

DATE MO	DY	YR	UT TIME HR	MN	SEC	S.M.AXIS(KM)	ECCENTRICITY	INCLIN(DEG)	ASC.NODE(DEG)	ARG.PER.(DEG)	MEAN ANOM.(DEG)
5	7	73	3	0	.000	.71991572E+04	[illegible]	.98E82E00E+02	.3238C049E+03	[illegible]	.10672665E+03
5	7	73	3	3	.000	.71991572E+04	[illegible]	[illegible]	.3238C254E+03	.24434136E+03	[illegible]
5	7	73	3	6	.000	.71991572E+04	[illegible]	[illegible]	.32388459E+03	[illegible]	[illegible]
5	7	73	3	9	.000	.71991572E+04	[illegible]	[illegible]	[illegible]	[illegible]	.14C65024E+03
5	7	73	3	12	.000	.71991572E+04	[illegible]	.98E82E00E+02	[illegible]	.24432331E+03	.15134477E+03
5	7	73	3	15	.000	.71991572E+04	[illegible]	[illegible]	.32381074E+03	.24431730E+03	.16199970E+03
5	7	73	3	18	.000	.71991572E+04	[illegible]	[illegible]	.32301279E+03	[illegible]	[illegible]
5	7	73	3	21	.000	.71991572E+04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	7	73	3	24	.000	.71991572E+04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	7	73	3	27	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	7	73	3	30	.000	[illegible]	[illegible]	.98E82E00E+02	.32382099E+03	.24422721E+03	[illegible]
5	7	73	3	33	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	7	73	3	36	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	7	73	3	39	.000	[illegible]	[illegible]	[illegible]	.32382714E+03	[illegible]	[illegible]
5	7	73	3	42	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	7	73	3	45	.000	[illegible]	[illegible]	[illegible]	.32383124E+03	[illegible]	[illegible]
5	7	73	3	48	.000	[illegible]	[illegible]	[illegible]	.32383329E+03	.24425111E+03	[illegible]
5	7	73	3	51	.000	[illegible]	[illegible]	[illegible]	.32383534E+03	[illegible]	[illegible]
5	7	73	3	54	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	7	73	3	57	.000	[illegible]	[illegible]	[illegible]	.32383944E+03	[illegible]	[illegible]
5	7	73	4	0	.000	[illegible]	[illegible]	[illegible]	.32384149E+03	[illegible]	[illegible]
5	7	73	4	3	.000	[illegible]	[illegible]	[illegible]	.32384354E+03	[illegible]	[illegible]
5	7	73	4	6	.000	[illegible]	[illegible]	[illegible]	.32384559E+03	[illegible]	[illegible]
5	7	73	4	9	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	7	73	4	12	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	7	73	4	15	.000	[illegible]	[illegible]	[illegible]	.32385174E+03	[illegible]	[illegible]
5	7	73	4	18	.000	[illegible]	[illegible]	[illegible]	.32385379E+03	[illegible]	[illegible]
5	7	73	4	21	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	7	73	4	24	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	7	73	4	27	.000	[illegible]	[illegible]	[illegible]	.32385994E+03	[illegible]	[illegible]
5	7	73	4	30	.000	[illegible]	[illegible]	[illegible]	.32386159E+03	[illegible]	[illegible]
5	7	73	4	33	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	7	73	4	36	.000	[illegible]	[illegible]	[illegible]	.32386609E+03	[illegible]	[illegible]
5	7	73	4	39	.000	[illegible]	[illegible]	[illegible]	.32386014E+03	[illegible]	[illegible]
5	7	73	4	42	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	7	73	4	45	.000	[illegible]	[illegible]	[illegible]	.32387224E+03	[illegible]	[illegible]
5	7	73	4	48	.000	[illegible]	[illegible]	[illegible]	.32387429E+03	[illegible]	[illegible]
5	7	73	4	51	.000	[illegible]	[illegible]	[illegible]	.32387634E+03	.24412475E+03	.14294423E+03
5	7	73	4	54	.000	[illegible]	[illegible]	[illegible]	.32387839E+03	.24411873E+03	[illegible]
5	7	73	4	57	.000	[illegible]	[illegible]	[illegible]	.32388044E+03	.24411271E+03	[illegible]
5	7	73	5	0	.000	[illegible]	[illegible]	.98E82E00E+02	.32388249E+03	.24411067CE+03	[illegible]
5	7	73	5	3	.000	[illegible]	[illegible]	[illegible]	.32388453E+03	[illegible]	.18556247E+03
5	7	73	5	6	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.19621700E+03
5	7	73	5	9	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	7	73	5	12	.000	[illegible]	[illegible]	[illegible]	.32389068E+03	[illegible]	.21752007E+03
5	7	73	5	15	.000	[illegible]	[illegible]	[illegible]	.32389273E+03	.24407661E+03	[illegible]
5	7	73	5	18	.000	[illegible]	[illegible]	[illegible]	.32389478E+03	[illegible]	[illegible]
5	7	73	5	21	.000	[illegible]	[illegible]	[illegible]	.32389683E+03	[illegible]	[illegible]
5	7	73	5	24	.000	[illegible]	[illegible]	.98E82E00E+02	.32389888E+03	[illegible]	[illegible]
5	7	73	5	27	.000	[illegible]	[illegible]	[illegible]	.32390093E+03	[illegible]	[illegible]
5	7	73	5	30	.000	[illegible]	[illegible]	.98E82E00E+02	.32390298E+03	[illegible]	.28145327E+03
5	7	73	5	33	.000	[illegible]	[illegible]	.98E82E00E+02	.32390503E+03	.24404051E+03	[illegible]
5	7	73	5	36	.000	[illegible]	[illegible]	[illegible]	.32390708E+03	[illegible]	[illegible]
5	7	73	5	39	.000	[illegible]	[illegible]	[illegible]	.32390913E+03	[illegible]	[illegible]
5	7	73	5	42	.000	[illegible]	[illegible]	[illegible]	.32391118E+03	[illegible]	[illegible]
5	7	73	5	45	.000	[illegible]	[illegible]	[illegible]	.32391323E+03	[illegible]	[illegible]
5	7	73	5	48	.000	[illegible]	[illegible]	[illegible]	.32391528E+03	[illegible]	[illegible]
5	7	73	5	51	.000	[illegible]	[illegible]	[illegible]	.32391733E+03	.24430441E+03	.35603501E+03
5	7	73	5	54	.000	[illegible]	[illegible]	[illegible]	.32391938E+03	[illegible]	.66695442E+01
5	7	73	5	57	.000	[illegible]	[illegible]	.98E82E00E+02	.32392143E+03	.24399237E+03	.17244079E+02

Figure 8. Sample Mean Element Printout

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PREPARED BY/FOR THE ANALYSIS AND SIMULATION BRANCH (SUA), AIR FORCE GEOPHYSICS LABORATORY, TELEPHONE 861-[illegible]

EPHEMERIS EXTRAPOLATION PROGRAM FOR SATELLITE NUMBER 10[illegible] PAGE 1[illegible]

DATE MO	DY	YR	U TIME HR	MN	SEC	X (KM)	Y (KM)	Z (KM)	XDOT (KM/SEC)	YDOT (KM/SEC)	ZDOT (KM/SEC)
5	3	73	0	0	.000	[illegible]	.242375396E+04	.404554876E+04	-.291261196E+01	.315755470E+01	[illegible]
5	[illegible]	[illegible]	0	3	.000	[illegible]	.344990286E+04	.239614776E+04	[illegible]	.256141105E+01	[illegible]
5	3	73	0	6	.000	[illegible]	[illegible]	.167552526E+04	-.751124703E+00	.167113010E+01	[illegible]
5	[illegible]	73	0	9	.000	[illegible]	.412456106E+04	.325332953E+03	.371753926E+00	[illegible]	[illegible]
5	3	73	0	12	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	3	73	0	15	.000	[illegible]	[illegible]	[illegible]	[illegible]	-.512657376E+00	[illegible]
5	3	73	0	18	.000	[illegible]	[illegible]	-.345795594E+04	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	0	21	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	0	24	.000	[illegible]	.332356206E+04	-.551002601E+04	[illegible]	[illegible]	[illegible]
5	3	73	0	27	.000	[illegible]	.277705126E+04	-.622056211E+04	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	0	30	.000	[illegible]	.217554546E+04	-.678725126E+04	[illegible]	[illegible]	[illegible]
5	3	73	0	33	.000	[illegible]	.140954096E+04	-.705661652E+04	[illegible]	[illegible]	-.227761755E+01
5	[illegible]	73	0	36	.000	[illegible]	[illegible]	-.705271916E+04	[illegible]	[illegible]	[illegible]
5	3	73	0	39	.000	[illegible]	-.127751275E+03	-.659052277E+04	.574365246E+01	[illegible]	[illegible]
5	[illegible]	73	0	42	.000	[illegible]	-.917555955E+03	[illegible]	.526102766E+01	[illegible]	[illegible]
5	[illegible]	[illegible]	0	45	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	0	48	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	0	51	.000	[illegible]	-.237710346E+04	[illegible]	.376510506E+01	[illegible]	[illegible]
5	[illegible]	73	0	54	.000	[illegible]	[illegible]	-.277231596E+04	[illegible]	-.314147926E+01	[illegible]
5	[illegible]	73	0	57	.000	[illegible]	[illegible]	-.151246534E+04	[illegible]	[illegible]	[illegible]
5	3	73	1	0	.000	[illegible]	-.410876966E+04	-.195333036E+03	[illegible]	-.103329716E+01	[illegible]
5	[illegible]	73	1	3	.000	[illegible]	-.425367336E+04	.114755136E+04	[illegible]	-.224743176E+00	[illegible]
5	[illegible]	73	1	6	.000	[illegible]	[illegible]	.244713116E+04	[illegible]	[illegible]	[illegible]
5	[illegible]	73	1	9	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	1	12	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	1	15	.000	[illegible]	-.377341506E+04	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	1	18	.000	[illegible]	[illegible]	.522579656E+04	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	1	21	.000	[illegible]	[illegible]	.631070636E+04	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	1	24	.000	[illegible]	-.135371546E+04	.706960026E+04	[illegible]	[illegible]	[illegible]
5	3	73	1	27	.000	[illegible]	-.550645566E+03	.707563256E+04	[illegible]	[illegible]	[illegible]
5	[illegible]	73	1	30	.000	-.211557436E+04	.209566776E+03	[illegible]	-.570149796E+01	[illegible]	[illegible]
5	[illegible]	73	1	33	.000	[illegible]	.949595745E+03	[illegible]	[illegible]	[illegible]	[illegible]
5	3	73	1	36	.000	[illegible]	.173467606E+04	.574372416E+04	[illegible]	[illegible]	[illegible]
5	[illegible]	73	1	39	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	1	42	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	3	73	1	45	.000	[illegible]	.337942626E+04	[illegible]	[illegible]	.245073656E+01	[illegible]
5	[illegible]	73	1	48	.000	[illegible]	[illegible]	[illegible]	[illegible]	.173374216E+01	[illegible]
5	[illegible]	73	1	51	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	1	54	.000	[illegible]	[illegible]	[illegible]	.170706216E+01	[illegible]	[illegible]
5	[illegible]	73	1	57	.000	[illegible]	[illegible]	[illegible]	.175626206E+01	-.665113206E+00	[illegible]
5	[illegible]	73	2	0	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	2	3	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	2	6	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	2	9	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	2	12	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	2	15	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	2	18	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	2	21	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	2	24	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	2	27	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	2	30	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	2	33	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	2	36	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	2	39	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	2	42	.000	[illegible]	[illegible]	.603517[illegible]E+03	[illegible]	[illegible]	[illegible]
5	[illegible]	73	2	45	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	2	48	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	2	51	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	73	2	54	.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	3	73	2	57	.000	[illegible]	-.316[illegible]E+04	.574760[illegible]E+04	[illegible]	[illegible]	[illegible]

Figure 9. Sample Position/Velocity Printout

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PREPARED BY/FOR THE ANALYSIS AND SIMULATION BRANCH (SUA), AIR FORCE GEOPHYSICS LABORATORY, TELEPHONE 861-4161

                 EPHEMERIS EXTRAPOLATION PROGRAM FOR SATELLITE NUMBER 10820                    PAGE    1

 SITE      UT TIME
 NO   Y  M  D   HR MN SEC
                      DELEV (DEG/SEC)      DAZI (DEG/SEC)                   DRTASC (DEG/SEC)      DDECL   (DEG/SEC)
                 ELEV.(DEG)     AZI.(DEG)   RANGE(KM)  (RANGE(KM/SEC)  RT.ASC.(DEG)  DECLIN(DEG)

10717.0                5   6  73        21   0     .000       75600.000            5262
   STATION NO.=**   -.376043E-01            .655753E-01          -.421523E-01          -.661466E-01
            -.712017E+01   .172542E+03   .426134E+04   .485363E+01   .177359E+03  -.296155E+02

10717.0                5   6  73        21   3     .000       75780.000            5262
   STATION NO.=**   -.365540E-01            .463515E-01          -.206616E-01          -.537339E-01
            -.135072E+02   .147052E+03   .518224E+04   .529522E+01   .171170E+03  -.403336E+02

10717.0                5   6  73        21   6     .000       75960.000            5262
   STATION NO.=**   -.350243E-01            .349493E-01          -.159036E-01          -.462339E-01
            -.193062E+02   .147770E+03   .614961E+04   .541499E+01   .166742E+03  -.492739E+02

10717.0                5   6  73        21   9     .000       76140.000            5262
   STATION NO.=**   -.337701E-01            .282213E-01          -.137505E-01          -.415925E-01
            -.257921E+02   .135549E+03   .712305E+04   .534207E+01   .163700E+03  -.571439E+02

10717.0                5   6  73        21  12     .000       76320.000            5262
   STATION NO.=**   -.329343E-01            .243527E-01          -.840247E-02          -.306564E-01
            -.315721E+02   .159330E+03   .806755E+04   .515495E+01   .161739E+03  -.643922E+02

10717.0                5   6  73        21  15     .000       76500.000            5262
   STATION NO.=**   -.320725E-01            .222570E-01          -.210145E-02          -.366226E-01
            -.374221E+02   .165432E+03   .957536E+04   .487370E+01   .160745E+03  -.711561E+02

10717.0                5   6  73        21  18     .000       76680.000            5262
   STATION NO.=**   -.314742E-01            .216183E-01           .105650E-01          -.351381E-01
            -.430181E+02   .164590E+03   .981735E+04   .451976E+01   .161336E+03  -.776512E+02

10717.0                5   6  73        21  21     .000       76860.000            5262
   STATION NO.=**   -.305674E-01            .222155E-01           .700250E-01          -.334305E-01
            -.460160E+02   .173046E+03   .105870E+05   .411054E+01   .166540E+03  -.836354E+02

10717.0                5   6  73        21  24     .000       77040.000            5262
   STATION NO.=**   -.703573E-01            .241303E-01           .126678E+01           .403563E-02
            -.541195E+02   .177663E+03   .112945E+05   .364189E+01   .243391E+03  -.804557E+02

10717.0                5   6  73        21  27     .000       77220.000            5262
   STATION NO.=**   -.297315E-01            .263116E-01           .631663E-01           .322586E-01
            -.555779E+02   .193481E+03   .119003E+05   .314149E+01   .316775E+03  -.835816E+02

10717.0                5   6  73        21  30     .000       77400.000            5262
   STATION NO.=**   -.285701E-01            .356434E-01           .131496E-01           .324916E-01
            -.648447E+02   .197377E+03   .124173E+05   .255097E+01   .322214E+03  -.777568E+02

10717.0                5   6  73        21  33     .000       77580.000            5262
   STATION NO.=**   -.275504E-01            .494109E-01           .331135E-02           .323194E-01
            -.679576E+02   .134948E+03   .128294E+05   .202731E+01   .323514E+03  -.720367E+02

10717.0                5   6  73        21  36     .000       77760.000            5262
   STATION NO.=**   -.249036E-01            .782110E-01          -.753619E-04           .321602E-01
            -.749140E+02   .215363E+03   .131356E+05   .143845E+01   .323743E+03  -.661756E+02

10717.0                5   6  73        21  39     .000       77940.000            5262
   STATION NO.=**   -.187531E-01            .137216E+00          -.159017E-02           .319064E-01
            -.701065E+02   .272315E+03   .133432E+05   .627262E+00   .323591E+03  -.604539E+02

10717.0                5   6  73        21  42     .000       78120.000            5262
   STATION NO.=**   -.255313E-02            .216311E+00          -.239326E-02           .316719E-01
            -.715036E+02   .294534E+03   .134324E+05   .206267E+00   .323225E+03  -.547429E+02
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Figure 10. Sample Station Observation Printout

[illegible] BY/FOR THE ANALYSIS AND SIMULATION BRANCH (SUA), AIR FORCE GEOPHYSICS LABORATORY, TELEPHONE 861-4161

[illegible] ASCENSION TEST

FLIGHT ALTITUDE = 10000M

SEGMENT NO.	MO DY YR	DAY	HR	MIN	SEC	AIRCRAFT LAT DEG	AIRCRAFT W.LONG DEG	AIRCRAFT-SATELLITE LOOKANGLES ELEV DEG	AZIM DEG	RANGE KM	RANRAT KM/SEC	300 KM SUB-ION LAT DEG	300 KM SUB-ION W.LONG DEG	SUB-SATELLITE LAT DEG	SUB-SATELLITE W.LONG DEG	REV NO.
1	3/27/79	86	20	54	0	-7.97	14.40	80.67	11.27	[illegible]	-.00	-7.55	14.32	-.19	12.86	8
1	3/27/79	86	20	55	0	-7.88	14.40	80.77	11.41	35836.	-.00	-7.47	14.32	-.19	12.86	8
1	3/27/79	86	20	56	0	-7.80	14.41	80.86	11.55	35830.	-.00	-7.40	14.32	-.19	12.86	8
1	3/27/79	86	20	57	0	-7.72	14.41	80.95	11.70	35834.	-.00	-7.32	14.33	-.19	12.86	8
1	3/27/79	86	20	58	0	-7.64	14.41	81.05	[illegible]	[illegible]	-.00	-7.24	14.33	-.19	12.86	8
1	3/27/79	86	20	59	0	-7.55	14.42	81.14	12.00	35831.	-.00	-7.16	14.33	-.19	12.86	8
1	3/27/79	86	21	0	0	-7.47	14.42	81.23	12.16	[illegible]	-.00	-7.08	14.34	-.18	12.86	8
1	3/27/79	86	21	1	0	-7.39	14.42	81.33	[illegible]	35828.	-.00	-7.01	14.34	-.18	12.86	8
1	3/27/79	86	21	2	0	-7.31	14.43	81.42	12.48	35827.	-.00	-6.93	14.34	-.18	12.86	8
1	3/27/79	86	21	3	0	-7.22	14.43	81.51	12.65	35825.	-.00	-6.85	14.35	-.18	12.86	8
1	3/27/79	86	21	4	0	-7.14	14.43	81.61	12.82	35824.	-.00	-6.77	14.35	-.18	12.86	8
1	3/27/79	86	21	5	0	-7.06	14.44	81.70	13.00	35823.	-.00	-6.69	14.35	-.18	12.86	8
1	3/27/79	86	21	6	0	-6.97	14.44	81.79	13.17	35821.	-.00	-6.61	14.36	-.18	12.86	8
1	3/27/79	86	21	7	0	[illegible]	14.44	81.89	13.36	35820.	-.00	-6.54	14.36	-.18	12.86	8
1	3/27/79	86	21	8	0	-6.81	14.45	81.98	13.54	35818.	-.00	-6.46	14.36	-.18	12.86	8
1	3/27/79	86	21	9	0	[illegible]	14.45	82.07	13.74	[illegible]	-.00	-6.38	14.36	-.18	12.86	8
1	3/27/79	86	21	10	0	-6.64	14.45	82.16	13.93	35816.	-.00	-6.30	14.37	-.18	12.85	8
1	3/27/79	86	21	11	0	-6.56	14.46	82.26	14.13	[illegible]	-.00	-6.22	14.37	-.18	12.85	8
1	3/27/79	86	21	12	0	[illegible]	14.46	82.35	14.34	35814.	-.00	-6.14	14.37	-.18	12.85	8
1	3/27/79	86	21	13	0	-6.40	14.46	82.44	14.55	35813.	-.00	-6.07	14.38	-.18	12.85	8
1	3/27/79	86	21	14	0	-6.31	14.47	82.53	14.76	35812.	-.00	-5.99	14.38	-.18	12.85	8
1	3/27/79	86	21	15	0	-6.23	14.47	82.63	14.98	35810.	-.00	-5.91	14.38	-.17	12.85	8
1	3/27/79	86	21	16	0	-6.15	14.47	82.72	15.21	35809.	-.00	-5.83	14.39	-.17	12.85	8
1	3/27/79	86	21	17	0	-6.07	14.48	82.81	15.44	35807.	-.00	-5.75	14.39	-.17	12.85	8
1	3/27/79	86	21	18	0	-5.98	14.48	82.90	15.68	35807.	-.00	-5.67	14.39	-.17	12.85	8
1	3/27/79	86	21	19	0	-5.90	14.48	82.99	15.93	35806.	-.00	-5.60	14.40	-.17	12.85	8
2	3/27/79	86	21	20	0	-5.85	14.39	83.08	15.14	35805.	-.00	-5.55	14.30	-.17	12.85	8
2	3/27/79	86	21	21	0	-5.80	14.29	83.17	14.73	35804.	-.00	-5.50	14.21	-.17	12.85	8
2	3/27/79	86	21	22	0	-5.74	14.19	83.25	13.90	35803.	-.00	-5.45	14.12	-.17	12.85	8
2	3/27/79	86	21	23	0	-5.69	14.09	83.34	12.86	35802.	-.00	-5.40	14.02	-.17	12.85	8
2	3/27/79	86	21	24	0	-5.64	13.99	83.42	11.79	35801.	-.00	-5.35	13.93	-.17	12.85	8
2	3/27/79	86	21	25	0	-5.59	13.89	83.50	10.91	35800.	-.00	-5.30	13.84	-.17	12.85	8
2	3/27/79	86	21	26	0	-5.54	13.80	83.58	9.98	35799.	-.00	-5.25	13.75	-.17	12.85	8
2	3/27/79	86	21	27	0	-5.49	13.70	83.66	9.05	35798.	-.00	-5.20	13.65	-.17	12.85	8
2	3/27/79	86	21	28	0	-5.43	13.60	83.74	8.09	35797.	-.00	-5.15	13.56	-.17	12.85	8
2	3/27/79	86	21	29	0	-5.38	13.50	83.81	7.11	35797.	-.00	-5.11	13.47	-.17	12.85	8
2	3/27/79	86	21	30	0	-5.33	13.40	83.89	[illegible]	35796.	-.00	-5.06	13.37	-.16	12.85	8
2	3/27/79	86	21	31	0	-5.28	13.31	83.96	5.17	35795.	-.00	-5.01	13.28	-.16	12.85	8
2	3/27/79	86	21	32	0	-5.23	13.21	84.03	[illegible]	35794.	-.00	-4.96	13.19	-.16	12.85	8
2	3/27/79	86	21	33	0	-5.17	13.11	84.09	2.44	35794.	-.00	-4.91	13.10	-.16	12.85	8
2	3/27/79	86	21	34	0	-5.12	13.01	84.16	1.04	35793.	-.00	-4.86	13.00	-.16	12.85	8
2	3/27/79	86	21	35	0	-5.07	12.91	84.22	.72	35792.	-.00	-4.81	12.91	-.16	12.85	8
2	3/27/79	86	21	36	0	-5.02	12.81	84.28	359.37	35792.	-.00	-4.76	12.82	-.16	12.85	8
2	3/27/79	86	21	37	0	-4.97	12.72	84.34	[illegible]	35791.	-.00	-4.71	12.72	-.16	12.85	8
2	3/27/79	86	21	38	0	-4.91	12.62	84.40	357.20	35791.	-.00	-4.66	12.63	-.16	12.85	8
2	3/27/79	86	21	39	0	-4.86	12.52	84.45	[illegible]	[illegible]	-.00	-4.61	12.54	-.16	12.85	8
2	3/27/79	86	21	40	0	-4.81	12.42	84.50	354.73	35790.	-.00	-4.56	12.45	-.16	12.85	8
2	3/27/79	86	21	41	0	-4.76	12.32	84.55	353.47	35789.	-.00	-4.51	12.35	-.16	12.85	8
2	3/27/79	86	21	42	0	-4.71	12.23	84.59	[illegible]	[illegible]	-.00	-4.47	12.26	-.16	12.85	8
2	3/27/79	86	21	43	0	-4.65	12.13	84.64	350.87	35788.	-.00	-4.42	12.17	-.15	12.85	8
2	3/27/79	86	21	44	0	-4.60	12.03	84.68	[illegible]	[illegible]	-.00	-4.37	12.07	-.15	12.85	8

Figure 11. Sample Aircraft Flight Printout

STATION NO.	MO DY YR	UNIVERSAL TIME DAY	HR	MIN	SEC	ELEV DEG	AZIM DEG	RANGE KM	ALT KM	RT ASC DEG	DECL DEG	SUB-SATELLITE LAT DEG	SUB-SATELLITE W.LONG DEG	SUN ELEV DEG	SAT ILLUM DEG	REV NO.
2	1/ 1/79	1	1	20	0	75.59	346.35	956.	832.20	230.37	-27.55	-33.87	246.28	47.1[illegible]	74.73	8146
2	1/ 1/79	1	1	21	0	50.27	345.70	1038.	828. 9	225.46	-2.88	-36.39	247.42	47.28	74.38	8146
2	1/ 1/79	1	1	22	0	33.63	345.13	1336.	825.85	222.11	13.46	-32.90	248.51	47.47	73.79	8146
2	1/ 1/79	1	1	23	0	22.77	344.81	1688.	822 9	219.71	24.05	-25.41	249.53	47.65	72.56	8146
2	1/ 1/7	1	1	24	0	15.14	344.58	2066.	819. 4	217.79	31.46	-25.90	250.50	47.63	71.96	8146
2	1/ 1/7	1	1	25	0	9.35	344.36	2457.	817 1	216.11	37.07	-22.40	251.43	48.02	70.74	8146
2	1/ 1/79	1	1	26	0	4.73	344.22	2654.	814.35	214.36	41.58	-18.88	252.33	46.20	69.34	8146
2	1/ 1/79	1	1	27	0	1.08	344.05	3255.	811 6	213.37	45.27	-15.36	253.20	46.38	67.77	8146
2	1/ 1/79	1	2	53	0	1.14	185.10	3353.	860.17	85.47	-48.66	-68.95	252.5[illegible]	63.03	68.60	8147
2	1/ 1/79	1	2	54	0	3.63	190.47	3052.	857. 5	94.46	-50.62	-65.74	256.55	63.18	70.05	8147
2	1/ 1/79	1	2	55	0	6.44	196.34	2773.	853 5	105.07	-51.53	-62.45	259.76	63.32	71.34	8147
2	1/ 1/79	1	2	56	0	9.13	204.85	2545.	850 57	119.23	-50.66	-59.10	262.37	63.47	72.45	8147
2	1/ 1/79	1	2	57	0	11.46	214.35	2362.	847.77	133.35	-47.39	-55.72	264.57	63.62	73.36	8147
2	1/ 1/79	1	2	58	0	13.08	226.31	2244.	843 4	146.32	-41.40	-52.31	266.45	63.77	74.07	8147
2	1/ 1/79	1	2	59	0	13.65	237.22	2201.	840 02	157.05	-33.21	-48.88	268.10	63.91	74.55	8147
2	1/ 1/79	1	3	0	0	12.99	249.16	2237.	837.32	165.37	-24.06	-45.44	269.57	64.06	74.81	8147
2	1/ 1/79	1	3	1	0	11.27	260.21	2350.	834 04	171.63	-14.69	-41.97	270.91	64.20	74.83	8147
2	1/ 1/79	1	3	2	0	8.85	269.82	2528.	830 01	176.31	-5.94	-38.50	272.12	64.34	74.61	8147
2	1/ 1/79	1	3	3	0	6.08	277.35	2759.	827 03	179.78	1.87	-35.02	273.26	64.49	74.16	8147
2	1/ 1/79	1	3	4	0	3.27	284.46	3029.	824 52	162.35	6.70	-31.52	274.32	64.63	73.48	8147
2	1/ 1/79	1	3	5	0	.77	289.86	3326.	821 51	164.24	14.63	-28.02	275.32	64.77	72.59	8147
2	1/ 1/79	1	9	24	0	1.11	128.93	3405.	881 08	113.46	-28.42	-53.72	207.65	26.46	34.47	8151
2	1/ 1/79	1	9	25	0	1.32	136.51	3376.	881.05	120.31	-33.47	-57.09	209.63	26.28	37.01	8151
2	1/ 1/7	1	9	26	0	1.13	144.12	3395.	881 4	128.26	-37.78	-60.44	211.97	26.09	39.53	8151
2	1/ 1/79	1	9	27	0	.71	151.52	3463.	881.64	137.17	-41.05	-63.74	214.77	25.91	42.04	8151
2	1/ 1/79	1	10	57	0	2.79	53.69	3185.	874. 5	82.59	23.04	-24.22	222.37	9.79	12.60	8152
2	1/ 1/79	1	10	58	0	6.20	60.12	2648.	876 9	83. 6	17.45	-27.67	223.31	9.58	15.09	8152
2	1/ 1/79	1	10	59	0	9.99	65.80	2532.	877.16	85.52	10.79	-31.12	224.30	9.41	17.61	8152
2	1/ 1/79	1	11	0	0	14.07	73.23	2246.	878.14	88.16	2.76	-34.56	225.34	9.24	20.14	8152
2	1/ 1/79	1	11	1	0	16.18	83.02	2007.	879 4	91.01	-6.53	-38.00	226.45	9.06	22.69	8152
2	1/ 1/79	1	11	2	0	21.75	95.64	1832.	879.02	97.09	-18.32	-41.43	227.64	8.89	25.25	8152
2	1/ 1/79	1	11	3	0	23.84	110.83	1743.	880 49	104.79	-30.75	-44.85	228.94	8.72	27.81	8152
2	1/ 1/79	1	11	4	0	23.62	126.36	1753.	881 04	116.00	-42.65	-48.27	230.37	8.55	30.37	8152
2	1/ 1/79	1	11	5	0	21.19	141.74	1860.	881 05	131.62	-51.88	-51.67	231.97	8.38	32.92	8152
2	1/ 1/79	1	11	6	0	17.46	153.80	2050.	881.70	150.62	-56.95	-55.05	233.79	8.21	35.47	8152
2	1/ 1/79	1	11	7	0	13.33	163.06	2301.	881 79	169.14	-57.97	-58.41	235.90	8.04	38.00	8152
2	1/ 1/79	1	11	8	0	9.30	173.07	2594.	881 0	183.13	-56.24	-61.74	238.40	7.88	40.52	8152
2	1/ 1/79	1	11	9	0	5.56	175.42	2917.	881.42	194.29	-53.47	-65.03	241.45	7.69	43.01	8152
2	1/ 1/79	1	11	10	0	2.24	179.57	3260.	880.92	201.53	-50.20	-68.25	245.27	7.52	45.46	8152
2	1/ 1/79	1	12	36	0	2.43	.71	3214.	871 1	44.79	46.18	-15.21	245.48	-6.16	6.24	8153
2	1/ 1/79	1	12	37	0	6.28	358.69	2631.	873.04	42.27	42.16	-16.67	246.34	-6.31	8.65	8153
2	1/ 1/79	1	12	38	0	10.89	356.34	2455.	874 05	39.37	37.37	-22.13	247.22	-6.46	11.10	8153
2	1/ 1/79	1	12	39	0	16.50	352.36	2091.	875 00	35.32	31.43	-25.58	248.14	-6.60	13.57	8153
2	1/ 1/79	1	12	40	0	23.52	346.37	1746.	876 01	31.52	23.70	-29.03	249.09	-6.75	16.06	8153
2	1/ 1/79	1	12	41	0	32.45	337.30	1444.	877 04	25.39	13.14	-32.48	250.10	-6.89	18.60	8153
2	1/ 1/79	1	12	42	0	43.04	321.56	1208.	878 08	18.24	-1.50	-35.92	251.16	-7.03	21.14	8153
2	1/ 1/79	1	12	43	0	51.13	291.63	1085.	879 32	7.08	-20.18	-39.35	252.30	-7.18	23.69	8153
2	1/ 1/79	1	12	44	0	48.68	255.15	1122.	880. 6	355.93	-38.75	-42.78	253.54	-7.32	26.25	8153
2	1/ 1/7	1	12	45	0	36.66	231.43	1297.	880. 8	323.13	-51.17	-46.20	254.88	-7.46	28.81	8153
2	1/ 1/79	1	12	46	0	26.63	213.82	1566.	881 16	306.22	-56.01	-49.61	256.38	-7.61	31.37	8153
2	1/ 1/79	1	12	47	0	20.58	211.55	1889.	881 50	287.77	-56.01	-53.00	258.06	-7.75	33.92	8153

Figure 12a. Sample Station Look Angle/Sub-Satellite/Occultation Printout

STATION NO.	MO DY YR	UNIVERSAL TIME DAY	HR	MIN	SEC	ELEV DEG	AZIM DEG	RANGE KM	ALT KM	300 KM SUB-ION LAT DEG	300 KM SUB-ION W.LONG DEG	SUB-SATELLITE LAT DEG	SUB-SATELLITE W.LONG DEG	SUN ELEV DEG	SAT ILLUM DEG	REV NO.
2	1/ 1/79	1	1	20	0	75.59	343.05	656.	832.20	-41.06	-114.02	-33.87	246.26	47.1	74.73	6146
2	1/ 1/79	1	1	21	0	50.27	345.70	1038.	828.19	-39.67	-113.53	-36.39	247.42	47.28	74.38	6146
2	1/ 1/79	1	1	22	0	33.63	345.13	1336.	825.65	-38.14	-113.00	-32.90	248.51	47.47	73.79	6146
2	1/ 1/79	1	1	23	0	22.77	344.81	1638.	822. 9	-36.39	-112.42	-29.41	249.53	47.65	72.98	6146
2	1/ 1/79	1	1	24	0	15.14	344.58	2066.	819 4	-34.33	-111.76	-25.90	250.50	47.83	71.96	6146
2	1/ 1/79	1	1	25	0	9.35	344.38	2457.	817 1	-31.36	-111.00	-22.40	251.43	48.02	70.74	6146
2	1/ 1/79	1	1	26	0	4.73	344.22	2854.	814 5	-28.96	-110.16	-18.88	252.33	48.21	69.34	6146
2	1/ 1/79	1	1	27	0	1.08	344.08	3255.	811 6	-25.64	-109.24	-15.36	253.20	48.38	67.77	6146
2	1/ 1/79	1	2	53	0	1.14	185.18	3353.	860..7	-58.40	-111.36	-66.95	252.50	63.03	68.60	6147
2	1/ 1/79	1	2	54	0	3.69	190.47	3052.	857 5	-55.65	-109.67	-65.74	256.55	63.17	70.05	6147
2	1/ 1/79	1	2	55	0	6.44	195.94	2779.	853.65	-53.19	-108.35	-62.45	255.76	63.32	71.34	6147
2	1/ 1/79	1	2	56	0	9.13	204.35	2545.	850. 7	-51.11	-107.26	-59.10	262.27	63.47	72.45	6147
2	1/ 1/79	1	2	57	0	11.46	214.35	2362.	847 .7	-49.10	-106.27	-55.72	264.57	63.62	73.26	6147
2	1/ 1/79	1	2	58	0	13.03	225.31	2244.	843 4	-47.36	-105.22	-52.31	266.45	63.77	74.07	6147
2	1/ 1/79	1	2	59	0	13.65	237.22	2201.	840.52	-45.76	-104.24	-48.38	268.10	63.91	74.55	6147
2	1/ 1/79	1	3	0	0	12.99	249.16	2237.	837 2	-44.22	-103.08	-45.44	269.57	64.06	74.81	6147
2	1/ 1/79	1	3	1	0	11.27	261.21	2350.	834 4	-42.52	-101.76	-41.97	270.91	64.20	74.83	6147
2	1/ 1/79	1	3	2	0	6.85	268.82	2526.	831 1	-40.39	-100.25	-38.50	272.13	64.34	74.61	6147
2	1/ 1/79	1	3	3	0	6.08	277.35	2759.	827 63	-38.94	-98.56	-35.02	273.26	64.49	74.16	6147
2	1/ 1/79	1	3	4	0	3.27	284.46	3029.	824 52	-36.71	-96.71	-31.52	274.32	64.63	73.46	6147
2	1/ 1/79	1	3	5	0	.77	293.88	3328.	821 31	-34.16	-94.77	-28.02	275.32	64.77	72.59	6147
2	1/ 1/79	1	9	24	0	1.11	128.93	3435.	881 8	-50.58	-134.64	-53.72	207.69	26.44	34.47	6151
2	1/ 1/79	1	9	25	0	1.32	135.51	3376.	881 5	-52.38	-132.65	-57.09	209.63	26.26	37.11	6151
2	1/ 1/79	1	9	26	0	1.19	144.12	3395.	881. 4	-54.22	-130.51	-60.44	211.57	26.09	39.53	6151
2	1/ 1/79	1	9	27	0	.71	151.52	3463.	881 04	-56.18	-128.96	-63.74	214.77	25.91	42.04	6151
2	1/ 1/79	1	10	57	0	2.73	55.69	3185.	874 15	-32.37	-128.66	-24.22	222.37	9.75	12.80	6152
2	1/ 1/79	1	10	58	0	6.20	61.12	2046.	876 9	-34.91	[illegible]	-27.67	223.31	9.58	15.09	6152
2	1/ 1/79	1	10	59	0	9.99	65.90	2532.	877 16	-37. 8	[illegible]	-31.12	224.30	9.41	17.61	6152
2	1/ 1/79	1	11	0	0	14.07	73.23	2246.	878 14	-38.44	-124.11	-34.56	225.34	9.24	20.14	6152
2	1/ 1/79	1	11	1	0	16.18	83.02	2007.	879. 4	-40.56	-122.92	-38.00	226.45	9.06	22.69	6152
2	1/ 1/79	1	11	2	0	21.75	95.64	1832.	879 .2	-42.02	-121.96	-41.43	227.64	8.89	25.25	6152
2	1/ 1/79	1	11	3	0	23.64	110.83	1743.	880 .9	-43.40	-121.01	-44.85	228.94	8.72	27.81	6152
2	1/ 1/79	1	11	4	0	23.62	126.36	1753.	881 4	-44.78	-120.21	-48.27	230.37	8.55	30.37	6152
2	1/ 1/79	1	11	5	0	21.19	141.74	1860.	881..5	-46.24	-119.46	-51.67	231.97	8.38	32.92	6152
2	1/ 1/79	1	11	6	0	17.46	153.89	2050.	881 70	-47.56	-118.75	-55.05	233.79	8.21	35.47	6152
2	1/ 1/79	1	11	7	0	13.33	163.36	2301.	881 79	-49.72	-117.98	-58.41	235.90	8.04	38.00	6152
2	1/ 1/79	1	11	8	0	9.30	170.07	2594.	881.70	-51.59	-117.07	-61.74	238.40	7.86	40.52	6152
2	1/ 1/79	1	11	9	0	5.56	175.42	2917.	881 .2	-54.02	-115.93	-65.03	241.45	7.69	43.01	6152
2	1/ 1/79	1	11	10	0	2.24	179.57	3260.	880.02	-57.30	-114.41	-68.25	245.27	7.52	45.48	6152
2	1/ 1/79	1	12	36	0	2.43	.71	3214.	871 1	-26.58	-114.40	-15.21	245.46	-6.16	6.24	6153
2	1/ 1/79	1	12	37	0	6.29	358.69	2631.	873. 4	-29.07	-113.89	-18.67	246.34	-6.31	8.65	6153
2	1/ 1/79	1	12	38	0	10.89	356.04	2455.	874 .5	-32.34	-113.44	-22.13	247.22	-6.46	11.10	6153
2	1/ 1/79	1	12	39	0	16.50	352.36	2031.	875 .0	-34.63	-113.05	-25.58	248.14	-6.60	13.57	6153
2	1/ 1/79	1	12	40	0	23.52	346.97	1748.	876 .1	-36.30	-112.70	-29.03	249.09	-6.75	16.08	6153
2	1/ 1/79	1	12	41	0	32.45	337.30	1444.	877..4	-38.13	-112.37	-32.46	250.10	-6.89	18.60	6153
2	1/ 1/79	1	12	42	0	43.04	321.56	1208.	878 8	-39.58	-112.04	-35.92	251.16	-7.03	21.14	6153
2	1/ 1/79	1	12	43	0	51.13	291.63	1388.	879 32	-40.93	-111.69	-39.35	252.30	-7.18	23.69	6153
2	1/ 1/79	1	12	44	0	48.65	255.15	1177.	880.	-42.24	-111.30	-42.78	253.54	-7.32	26.25	6153
2	1/ 1/79	1	12	45	0	38.66	231.43	1237.	880 .8	-43.51	-110.84	-46.20	254.86	-7.46	28.81	6153
2	1/ 1/79	1	12	46	0	26.63	213.32	1566.	881 16	-45.10	-110.26	-49.61	256.28	-7.61	31.37	6153
2	1/ 1/79	1	12	47	0	20.58	211.55	1889.	881 50	-46.80	-109.58	-53.00	258.46	-7.75	33.93	6153

Figure 12b. Sample Station Look Angle/Sub-Ionosphere/Sub-Satellite/Occulation Printout

If a user requires only the type of output illustrated by Figure 12a or 12b, columns 2, 4, 6, and 8 of card 6 should all be zero, and the deck should include at least one station card. However, if the user elects another print option (i.e., columns 2, 4, 6, and 8 of card 6 not all zero), the Figure 12 printout will also be furnished (in addition to type of printout specifically requested) if a station card is present in the deck.

The satellite illumination angle shown in Figures 12a and 12b measures the elevation of the center of the solar disk above the satellite's Earth-horizon. Figure 13 illustrates the geometry. The plane of the drawing is that plane which passes through the center of the Earth, the center of the sun, and the satellite's location. Positive values of illumination angle imply that the satellite is illuminated by the Sun; for negative values, the satellite is immersed in the Earth's shadow.

The solar elevation angle listed on Figures 12a and 12b is simply the elevation of the Sun at the location of the specified station.

The station parameters right ascension and declination shown on Figure 12a are topocentric coordinates of the satellite. They represent the orientation of the station-to-satellite vector referenced to the equatorial plane and the direction of the vernal equinox.

2.1.5 Output Files

The standard ephemeris file available from LOKANGL is designated TAPE3. It is written in Subroutine SPPROU. The format of this file is shown in Table 4. Not only is it available as an external output of the program, but it is also used internally by Subroutine WRS1P to obtain the parameters necessary to calculate and print certain types of output.

Graphical display and analysis of apogee/perigee data is a sensitive tool for assessing the caliber of ephemeris calculations. TAPE7 is a file which provides the input data to Program PLOTIT for display of apogee/perigee information. The structure of a TAPE7 record is shown in Table 5.

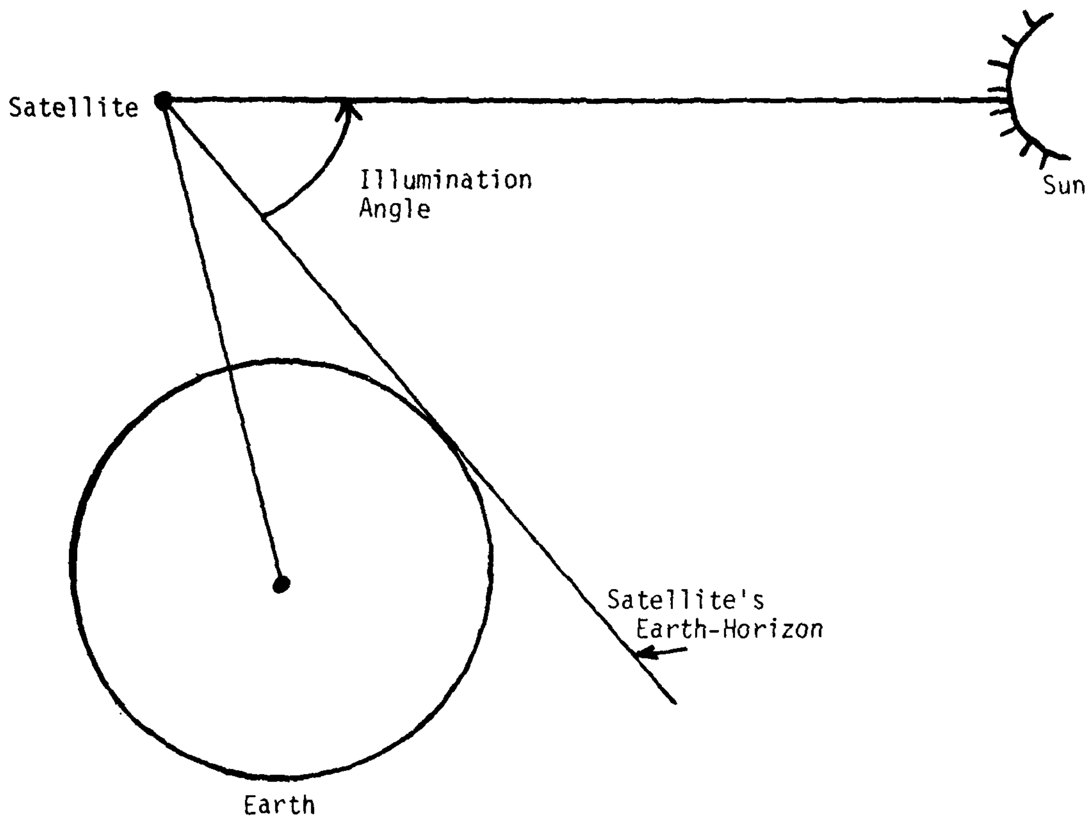

Figure 13. Geometry of the Illumination Angle

TAPE3 BINARY FORMAT PRODUCED BY SUBROUTINE SPPROU IS AS FOLLOWS

FIRST RECORD	IDENTIFICATION RECORD
WORD	DEFINITION
1. KF7	7,NUMBER OF WORDS REMAINING IN THIS RECORD
2. NOSAT	SATELLITE NUMBER
3. TIMSEC(1)	TIME OF DAY OF INITIAL PRINT TIME (SEC)
4. DJUPRT(1)	MODIFIED JULIAN DATE OF FINAL PRINT TIME
5. TIMSEC(2)	TIME OF DAY OF FINAL PRINT TIME
6. DJUPRT(2)	MODIFIED JULIAN DATE OF FINAL PRINT TIME
7. DPRINT	PRINT INTERVAL (SEC)
8. NOSPRI	NUMBER OF SPECIAL PRINT TIMES

DATA RECORDS	THIS RECORD IS REPEATED FOR EVERY PRINT TIME
WORD	DEFINITION
1. WERASE(1)	NUMBER OF WORDS REMAINING IN THIS RECORD= 32 + 11*IJ
2. DAYJL	MODIFIED JULIAN DATE OF THE EPHEMERIS PRINT TIME
3. KMOOUT	CALENDAR MONTH
4. KDAOUT	CALENDAR DAY
5. KYROUT	CALENDAR YEAR (LAST 2 DIGITS OF 19XX)
6. KHROUT	HOUR OF DAY
7. KMIOUT	MINUTE OF HOUR
8. SECOUT	SECONDS OF MINUTE
9. TWORMO	TIME OF DAY IN SECONDS CORRESPONDING TO DAYJL
10. DV(1)	X COORDINATE OF POSITION VECTOR (KM)
11. DV(2)	Y COORDINATE OF POSITION VECTOR (KM)
12. DV(3)	Z COORDINATE OF POSITION VECTOR (KM)
13. DV(4)	X-DOT COORDINATE OF VELOCITY VECTOR (KM/SEC)
14. DV(5)	Y-DOT COORDINATE OF VELOCITY VECTOR (KM/SEC)
15. DV(6)	Z-DOT COORDINATE OF VELOCITY VECTOR (KM/SEC)
16. ALTIO	SATELLITE ALTITUDE (KM)
17. RADPRT	SATELLITE GEOCENTRIC DISTRANCE (KM)
18. VTOTPR	VELOCITY (KM/SEC)
19. GEOCEN	GEOCENTRIC LATITUDE (DEG)
20. GEODET	GEODETIC LATITUDE (DEG)
21. OLAMO	SATELLITE LONGITUDE (DEG)
22. MSTHR	HOUR OF GREENWICH MEAN SIDEREAL TIME
23. MSTMIN	MINUTE OF GREENWICH MEAN SIDEREAL TIME
24. STSECO	SECONDS OF GREENWICH MEAN SIDEREAL TIME
25. AXSEMI	SEMI-MAJOR AXIS (KM)
26. ECCEN	ECCENTRICITY
27. XOINCL	INCLINATION (DEG)
28. XWASC	RIGHT ASCENSION OF ASCENDING NODE (DEG)
29. XWPERI	ARGUMENT OF PERIGEE (DEG)
30. XKMEAN	MEAN ANOMALY (DEG)
31. IREV	REVOLUTION NUMBER
32. IJ	NUMBER OF STATIONS IN THIS DATA RECORD (<21)
33. ITYPE	=1, FINAL WORD IF IJ=0
34. NUMSTA	STATION NUMBER
35. ELRATE	ELEVATION RATE (DEG/SEC)
36. AZRATE	AZIMUTH RATE (DEG/SEC)
37. RARATE	RIGHT ASCENSION RATE (DEG/SEC)
38. DCRATE	DECLINATION RATE (DEG/SEC)
39. ELEVAT	ELEVATION (DEG)
40. AZIMUT	AZIMUTH (DEG)
41. RANGES	RANGE (KM)
42. RANRAT	RANGE RATE (KM/SEC)
43. RTASC	RIGHT ASCENSION (DEG)
44. CLIN	DECLINATION (DEG)

THE SEQUENCE OF WORDS 34 TO 44 IS REPEATED IJ TIMES

FINAL RECORD	IDENTIFICATION RECORD FOR THE END OF PROBLEM
WORD	DEFINITION
1. KF1	1
2. BLANK	HOLLERITH BLANKS

AN END OF FILE FOLLOWS THIS RECORD

Table 4. Structure of TAPE3 Ephemeris File

WORD #	QUANTITY	FORMAT
1	Day Number	I3
2	Hour	I2
3	Minute	I2
4	Year	I2
5	Perigee Latitude	F6.2
6	Perigee W. Longitude	F6.2
7	Altitude of Perigee (Kms)	F8.1
8	Apogee Latitude	F6.2
9	Apogee W. Longitude	F6.2
10	Altitude of Apogee (Kms)	F8.1
11	Rev Number	I9
12	Local Time of Perigee (Hours)	F6.2
13	Local time at Apogee (Hours)	F6.2

Table 5. Structure of Record for TAPE7, Apogee/Perigee File

Several plotting capabilities have been developed for displaying conditions of eclipsing of the satellite by the Earth in support of the SCATHA Program. These displays make use of the satellite illumination angle, a quantity that is not available from either TAPE3 or TAPE7. It is calculated in subroutine WRSTP, which, using the CDC UPDATE cards shown in Table 6, can be modified to produce TAPE2 which contains the data necessary for the eclipse plots. Table 7 summarizes the structure of a TAPE2 record.

```
ATTACH, OLDPL, LOKPLX3421, ID=ROBERTS, MR=1.
REQUEST, TAPE2, *PF.
UPDATE (F)
FTN, I.
LDSET (PRESET=ZERO)
LGO (PL=77777)
CATALOG, TAPE2, SPR79, ID=BREHM.
7/8/9
*ID NOV6
*D LOKANG.3
     *TAPE2, TAPE7) (Continuation Card)
*I WRSTP.154
  367 WRITE (2) LMONTH, LDAY, LYEAR, JHOUR, JMIN, JSEC, SLAT, SLON, XILLM,
     *ALTIO, IDAY, RADPRT, KK (Continuation Card)
7/8/9
     - Data Cards -
6/7/8/9
- The following UPDATE modifications can be used to suppress listed output -
*D WRSTP·151,WRST·152
*D WRSTP.41
      Go to 300
```

Table 6. Control Cards and UPDATE Cards for Creating TAPE2

Word Number	Variable Name	Variable
1	LMONTH	Calendar Month
2	LDAY	Calendar Day
3	LYEAR	Calendar Year
4	JHOUR	Hour of Day
5	JMIN	Minute of Hour
6	JSEC	Second of Minute
7	SLAT	Sub-Satellite Latitude
8	SLON	Sub-Satellite Longitude (West)
9	XILLM	Satellite Illumination Angle
10	ALTIO	Satellite Altitude (Kms)
11	IDAY	Julian Day
12	RADPRT	Satellite Geocentric Distance (Kms)
13	KK	Station Number

Table 7. Structure of TAPE2 Record

2.1.6 Error Checks

Several safeguards have been built into the program to diagnose errors commonly encountered in practice. They are listed in Table 8.

Error Condition Checks	Internal and External Indications	Recovery Procedures or Action Required
Thrust Cards	"Error-Thrust Cards out of sequence"	Correct Input Data Cards
Number of Stations	"Station printout requested, NMS must not equal zero"	Correct Input Data Cards
Time Interval	"Print interval is negative or zero"	Correct Input Data Cards
Print Times	"Start print time is greater than end print time"	Correct Input Data Cards
NOSPRI	"NOSPRI, number of special points is negative or exceeds 120"	Correct Input Data Cards
ID of Stations on TAPE3 correspond with input ID's?	"Station which is on TAPE3 does not agree with any of the INPUT stations. Program cannot continue"	Identify source of erroneous ID on TAPE3 and correct

Table 8. Error Checks

2.1.7 Graphics

There are no graphics within LOKANGL itself. However TAPE2 and TAPE7 are intended specifically for plotting applications. TAPE2 is used for those plotting applications that involve evaluation of elipsing conditions. TAPE3, the general purpose ephemeris file, is also useful for various plotting purposes.

TAPE7 is used in conjunction with Program PLOTIT to generate apogee/perigee plots. These displays can be used as a sensitive diagnostic for evaluating the quality of ephemeris calculations, especially for those cases in which a long time interval is spanned by multiple element sets. Non-physical features in these plots, such as discontinuous derivatives, often reveal errors in the corresponding element sets.

Figure 14 is an example of a plot generated by PLOTIT. Table 9 illustrates the setup of the input deck for PLOTIT. Table 10 illustrates a typical run-deck for a combined LOKANGL/PLOTIT run. Compiled versions of both programs have been assumed available.

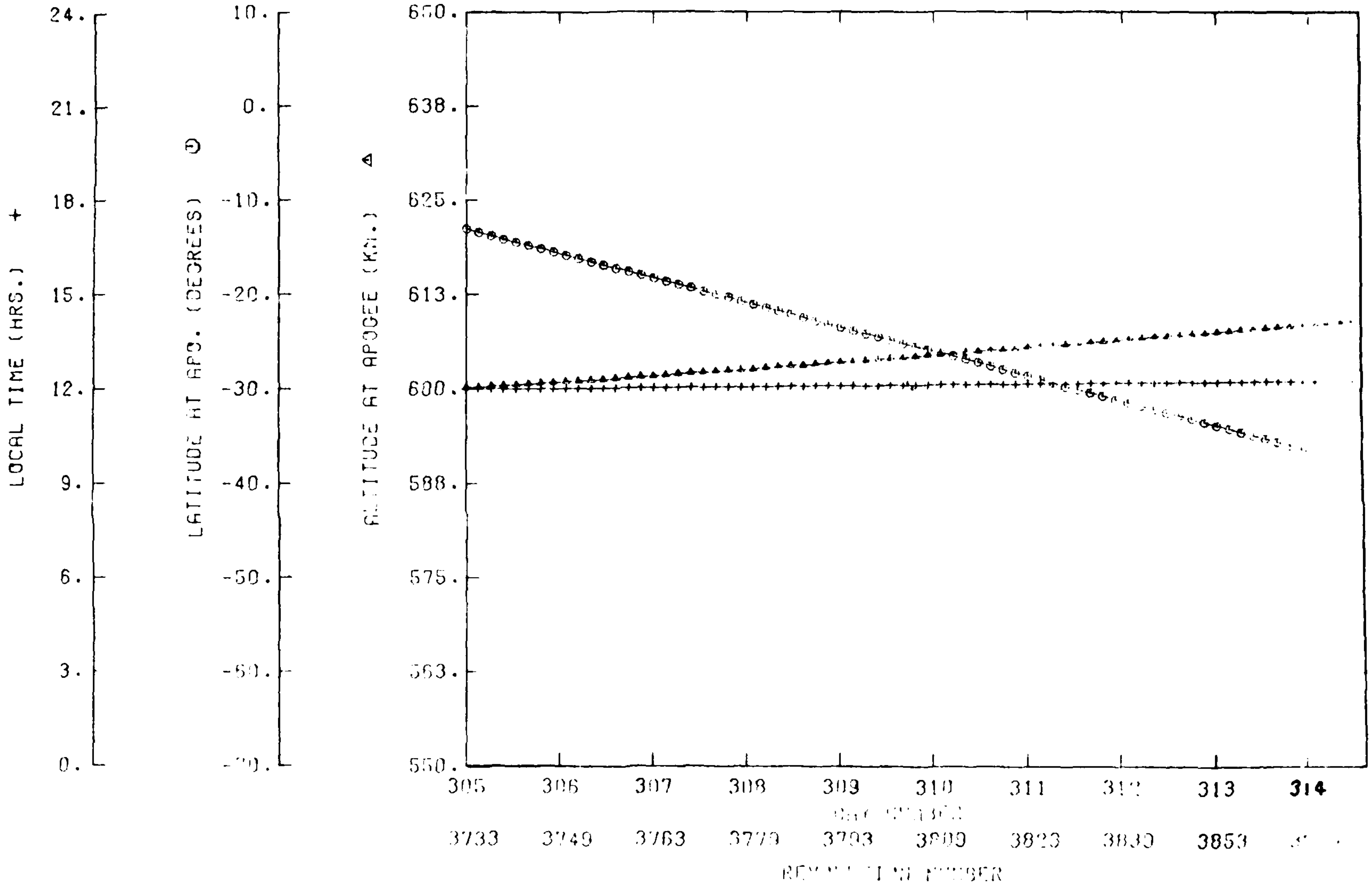

Figure 14. Example of Apogee Plot Generated by PLOTIT

```
*****************************************************************
*****************************************************************
*****************************************************************
                    ***** DATA DECK SETUP *****
CARD     COLS                                         FORMAT
  1      1-2    "1"       NPASS                       I2
  NPASS IS THE NUMBER OF PROBLEMS.
  THRUST CARDS ARE ENTERED NEXT AS FOLLOWS...
         1-3     TIME IN DAYS OF THRUST OCCUR
                 ENCE                                 I3
         5-9     SECONDS OF DAY OF THRUST             I5
          .
          .
          .
  N              LAST THRUST CARD.
 N+1     1-2     "-1"(INDICATES END OF THR.)          I2
 N+2     1-2     VARIABLE FIELD NUMBER                I2
         4-8     VARIABLE ABBREVIATION                A5
         11-50   AXIS LABEL FOR VARIABLE              4A10
         51-52   VAR. SYM. CODE NUMBER                I2
         54-56   FIX OR FLO                           A3
         58-62   LOWER LIMIT OF VARIABLE              F5.0
         63-67   UPPER LIMIT OF VARIABLE              F5.0
         68-72   Y AXIS HEIGHT IN INCHES              F5.0

         73-74   NUMBER OF DIGITS TO RT. OF .I2
                 IF COLS 54-56 ARE FLO. IF
                 COLS 54-56 ARE FIX, THEN
                 COLS 73-74 CONTAIN THE NUM-
                 BER OF DIGITS.

*****************************************************************

THERE MAY BE AS MANY AS 15 MORE "N+2" CARDS, ONE PER VARIABLE.
NOTE...THE FIRST "N+2" CARD DESIGNATES THE X-AXIS.

IF THE FIRST "N+2" CARD HAS AS ITS VARIABLE ABBREVIATION "DAY",
THEN THE DAY NUMBER (X-AXIS) IS CALCULATED ASSUMING THAT THE
FIRST THREE FIELDS OF THE VARIABLE DATA CARD CONTAIN 1.)THE DAY
NUMBER, 2.)THE HOUR, AND 3.) THE MINUTE.
*****************************************************************

 N+3     1-80    BLANK(INDICATES END OF "N+2"
                 CARDS)
NCASES IS THE NUMBER OF DATA DECKS.
MULTIP(I,K) CONTAINS THE VARIABLE FIELD NUMBER.  IT ALLOWS UP TO
6 MULTIPLE PLOTS EACH HAVING AS MANY AS 5 VARIABLES (RT. JUSTI
FIED)
IF(IPLT(I).EQ.1), THE FIELD CONTAINING THE "1" (E.G. THE 10TH
I2 FIELD) WILL INSURE THE PLOTTING OF THE VARIABLE WHOSE FIELD
NUMBER IS ,IN THIS CASE, 10.
 N+4     1-32    NCASES,TSUMRY(I).                    16I2
 N+5     1-60    MULTIP(I,K)                          6(5I2)
 N+6     1-32    "15",IPLT(I)                         16I2
 N+7     1-60    SATELLITE AND MODEL USED             6A10
        69-70    VARIABLE DATA FILE NUMBER   (1=CARD INPUT)
*****************************************************************
NEXT COMES THE VARIABLE DATA
  FORMAT(I3,2I2,2F6.2,F8.1,2F6.1,F8.1,I9,2F6.2,I2,2X,A6)
THIS DATA MUST BE FOLLOWED BY AN END OF FILE, AND THE
SATELLITE AND MODEL USED CARD, AND VARIABLE DATA
(N+7 ON) IS REPEATED FOR NEXT NCASE
*****************************************************************
*****************************************************************
```

Table 9. Setup of Input Cards for PLOTIT

```
LOMEB,CM135300.                    2265 PLOTTING          2265     BREHM
ATTACH,BB,LOKBINX3421,ID=BREHM,MR=1.
LDSET,PRESET=ZERO.
BB,PL=77777.
REWIND,TAPE7.
REQUEST,PLOT,*Q.
ATTACH,PEN,ONLINEPEN,MR=1.
LIBRARY,PEN.
ATTACH,BIN,PLOTBINX3421,ID=BREHM,MR=1.
LDSET,PRESET=ZERO.
BIN,PL=77777.
DISPOSE,PLOT,*PL.
EOR
1
  2265X              80311          0.0            9291
3890.15670259 3.74076-5171.2744-3.7342943-4.2379691-4.9372964
  2265X              80318          0.0            9396
3829.3062534 64.00054-4570.7173-2.7934218-4.3326414-5.4365726
  2265X              80325          0.0            9501
3593.4190741 46.40038-4362.9465-2.0314623-4.4038131-5.7322675
  2265X              80332          0.0            9606
3012.3997546 40.90393-4217.8634-1.4060863-4.4330925-5.9174672
  2265X              80339          0.0            9711
2422.4371349 13.47955-4074.7996-.8913014 9-4.6952317-5.8723374
 0
85400.0           11 01 80 00.0 00.0 00.000 12 31 80 00.0 00.0 00.000
 0 0 0 0-11.0
END OF PROBLEM
9
EOR
 1
-1
 1 DAY    DAY NUMBER                                  FIX   305.  335.
05 LATIT  LATITUDE AT PER. (DEGREES)               01 FLO   -10.   70.  8.    C
07 ALTIT  ALTITUDE AT PERIGEE (KM.)                02 FLO   475.  575.  8.    C
08 LATIT  LATITUDE AT APO. (DEGREES)               01 FLO   -70.   10.  8.    C
10 ALTIT  ALTITUDE AT APOGEE (KM.)                 02 FLO   550.  650.  8.    C
12 LOCTT  LOCAL TIME (HRS.)                        03 FLO     0.   24.  8.    C
13 LOCTI  LOCAL TIME (HRS.)                        07 FLO     0.   24.  8.    C
BLANK
1
    12 5 7    13 810
1
11/85 2265                                                        7
EOF
```

Table 10. Setup of Deck for Combined LOKANGL/PLOTIT Run

2.1.8 Computer Requirements

As currently configured, LOKANGL requires 67K octal core memory. Compilation uses 15 seconds of central processor time. The run time for a given job can be estimated by:

$$\text{Run Time} = \frac{T_{final} - T_{initial}}{t} \times (C) \qquad \text{seconds}$$

where t is the time step size

and C is a number between 0.01 and 0.04 (CP time for one calculation).

2.2 Solar-Magnetospheric Coordinates

2.2.1 Introduction

The geocentric solar magnetospheric (SM) coordinate system is defined to be a set of rectangular axes with the X-axis pointing in the direction from the Earth's center to the Sun. The Y-axis is perpendicular to the plane containing the X-axis and the Earth's magnetic dipole axis. The Z-axis is directed in the same sense as the nothern magnetic pole.

In this system the Y-axis is always in the magnetic equatorial plane and lies in the dawn-dusk meridian, oriented towards dusk. As the Earth's magnetic dipole rotates about the Earth's rotational axis, this system of coordinates rocks about the solar direction with a 24-hour period. An important feature is that, in this system, the otherwise three dimensional motion of the Earth's dipole is reduced to motion in a plane (the X-Z plane). The system finds application in areas of magnetospheric physics such as the interaction of the solar wind with the Earth's magnetic field.

To exploit the advantage of SM coordinates, a capability for expressing satellite ephemerides in this system has been incorporated into a version of Program LOKANGLE: SMLOK.

2.2.2 Approach

Satellite position and velocity in Earth Centered Inertial (ECI) rectangular coordinates are available within subroutine SPPROU (See Section 2.1). For the SM modification, a software module which transforms from ECI to SM coordinates has been added to SPPROU. The SM coordinates are then written to a modified ephemeris file, TAPE3, which can then be made available for purposes external to SMLOK.

2.2.3 Input/Output

Input to SMLOK is identical to that of a normal LOKANGL run (see Section 2.1.3). The output listing is shown in Figure 15. TAPE3, the SMLOK ephemeris file, has the structure of the normal LOKANGL TAPE3, except that ECI rectangular coordinates are replaced by solar magnetospheric, preserving the X, Y, Z ordering.

A modified version of the SCATHA 5-in-1 plotting routine has been used to plot SM coordinates. An example is shown in Figure 16 for the SCATHA vehicle.

MO DY YR	HR	MN	SEC	LATITUDE	W. LONG.	ILLUM	ALTITUDE	JDAY	RAD. DIST.	SOLAR MAGNETOSPHERIC COORDS SMX (KM)	SMY (KM)	SMZ (KM)	STA
3/ 2/7	16	9		1.0	104.76	125.51	3579 . 6	61	42168.21	29400.4	-29[illegible]7.63	5480.64	31
3/ 2/7	16	10	0	1.00	104.36	125.75	35790.30	61	42168.46	29528.94	-29601.91	5472.45	31
3/ 2/7	16	11		1. 1	104.76	126.00	3579 .54	61	42168.70	29656.82	-29475.63	5464.36	31
3/ 2/7	16	12		1.02	104.36	126.25	35790.78	61	42168.94	29784.13	-29348.61	5456.37	31
3/ 2/7	16	13	0	1. 3	104.76	126.49	35791.02	61	42169.18	29910.89	-29221.44	5448.49	31
3/ 2/7	16	14		1.04	104.76	126.73	35791.26	61	42169.42	31037.06	-29[illegible]3.52	5440.71	31
3/ 2/7	16	15	0	1.05	104.36	126.97	35791.50	61	42169.66	30162.67	-28965.07	5433.04	31
3/ 2/7	16	16		1.05	104.36	127.22	35791.74	61	42169.90	30287.71	-28836.07	5425.48	31
3/ 2/7	16	17		1.06	104.36	127.46	35791.98	61	42170.14	30412.17	-28706.54	5418.03	31
3/ 2/7	16	18		1.07	104.36	127.71	35792.22	61	42170.38	30536.05	-28576.47	5410.69	31
3/ 2/7	16	19	0	1.08	104.76	127.95	35792.46	61	42170.62	30659.35	-28445.68	5403.47	31
3/ 2/7	16	20	0	1.09	104.36	128.19	35792.70	61	42170.86	30762.07	-28314.75	5396.36	31
3/ 2/7	16	21		1.09	104.36	128.43	35792.94	61	42171.10	30904.20	-28183.10	5389.37	31
3/ 2/7	16	22		1.1	104.36	128.68	35797.18	61	42171.34	31025.74	-28051.52	5332.50	31
3/ 2/7	16	23		1.11	104.76	128.92	35793.42	61	42171.58	31146.69	-27918.22	5375.76	31
3/ 2/7	16	24		1.12	104.76	129.16	35793.66	61	42171.82	31267.05	-27785.10	5369.13	31
3/ 2/7	16	25		1.13	104.36	129.41	35793.90	61	42172.06	31386.82	-27651.26	5362.63	31
3/ 2/7	16	26		1.13	104.76	129.65	35794.14	61	42172.30	31505.98	-27517.01	5356.26	31
3/ 2/7	16	27		1.14	104.36	129.89	35794.38	61	42172.54	31624.55	-27382.25	5350.02	31
3/ 2/7	16	28		1.15	104.36	130.13	35794.62	61	42172.78	31742.52	-27246.98	5343.90	31
3/ 2/7	16	29		1.16	104.36	130.38	35794.86	61	42173.01	31859.88	-27111.21	5337.92	31
3/ 2/7	16	30		1.17	104.36	130.62	35795.10	61	42173.25	31976.64	-26974.93	5332.07	31
3/ 2/7	16	31		1.17	104.36	130.86	35795.34	61	42173.49	32092.79	-26838.15	5326.36	31
3/ 2/7	16	32		1.19	104.76	131.10	35795.58	61	42173.73	32208.33	-26700.87	5320.78	31
3/ 2/7	16	33		1.19	104.36	131.35	35795.81	61	42173.97	32323.25	-26563.10	5315.34	31
3/ 2/7	16	34	0	1.20	104.36	131.59	35796.05	61	42174.21	32437.55	-26424.83	5310.04	31
3/ 2/7	16	35	0	1.21	104.36	131.83	35796.29	61	42174.45	32551.26	-26286.08	5304.88	31
3/ 2/7	16	36		1.21	104.36	132.07	35796.53	61	42174.69	32664.33	-26146.84	5299.66	31
3/ 2/7	16	37		1.22	104.76	132.31	35796.77	61	42174.92	32776.78	-26007.11	5294.99	31
3/ 2/7	16	38	0	1.23	104.36	132.55	35797.01	61	42175.16	32888.61	-25866.9[illegible]	5290.26	31
3/ 2/7	16	39		1.24	104.36	132.80	35797.24	61	42175.40	32999.82	-25726.21	5285.68	31
3/ 2/7	16	40	0	1.24	104.36	133.04	35797.48	61	42175.64	33110.40	-25585.04	5281.25	31
3/ 2/7	16	41		1.25	104.76	133.29	35797.72	61	42175.87	33220.34	-25443.41	5276.97	31
3/ 2/7	16	42	0	1.26	104.76	133.52	35797.96	61	42176.11	33329.66	-25301.30	5272.84	31
3/ 2/7	16	43	0	1.27	104.76	133.76	35798.19	61	42176.35	33438.34	-25158.72	5268.86	31
3/ 2/7	16	44		1.27	104.36	134.00	35798.43	61	42176.59	33546.38	-25015.68	5265.04	31
3/ 2/7	16	45		1.28	104.76	134.24	35798.67	61	42176.82	33653.79	-24872.17	5261.37	31
3/ 2/7	16	46		1.29	104.37	134.48	35798.91	61	42177.06	33760.56	-24728.21	5257.86	31
3/ 2/7	16	47	0	1.30	104.37	134.73	35799.14	61	42177.30	33866.68	-24583.78	5254.50	31
3/ 2/7	16	48		1.30	104.37	134.97	35799.38	61	42177.53	33972.16	-24438.91	5251.31	31
3/ 2/7	16	49		1.31	104.37	135.21	35799.61	61	42177.77	34077.00	-24293.58	5248.27	31
3/ 2/7	16	50		1.32	104.37	135.45	35799.85	61	42178.00	34181.18	-24147.81	5245.40	31
3/ 2/7	16	51		1.33	104.37	135.69	35800.09	61	42178.24	34284.72	-24001.59	5242.69	31
3/ 2/7	16	52		1.33	104.37	135.93	35800.32	61	42178.47	34387.60	-23854.92	5240.15	31
3/ 2/7	16	53		1.34	104.37	136.17	35800.56	61	42178.71	34489.83	-23707.82	5237.77	31
3/ 2/7	16	54		1.35	104.37	136.41	35800.79	61	42178.94	34591.41	-23560.29	5235.56	31
3/ 2/7	16	55		1.36	104.37	136.65	35801.03	61	42179.18	34692.33	-23412.30	5233.51	31
3/ 2/7	16	56		1.36	104.37	136.89	35801.26	61	42179.41	34792.59	-23263.90	5231.64	31
3/ 2/7	16	57	0	1.37	104.37	137.13	35801.49	61	42179.65	34892.18	-23115.07	5229.94	31
3/ 2/7	16	58		1.38	104.37	137.37	35801.73	61	42179.88	34991.11	-22965.81	5228.40	31
3/ 2/7	16	59	0	1.39	104.37	137.61	35801.96	61	42180.12	35089.38	-22816.13	5227.04	31

Figure 15. Sample Solar/Magnetospheric Ephemeris Printout

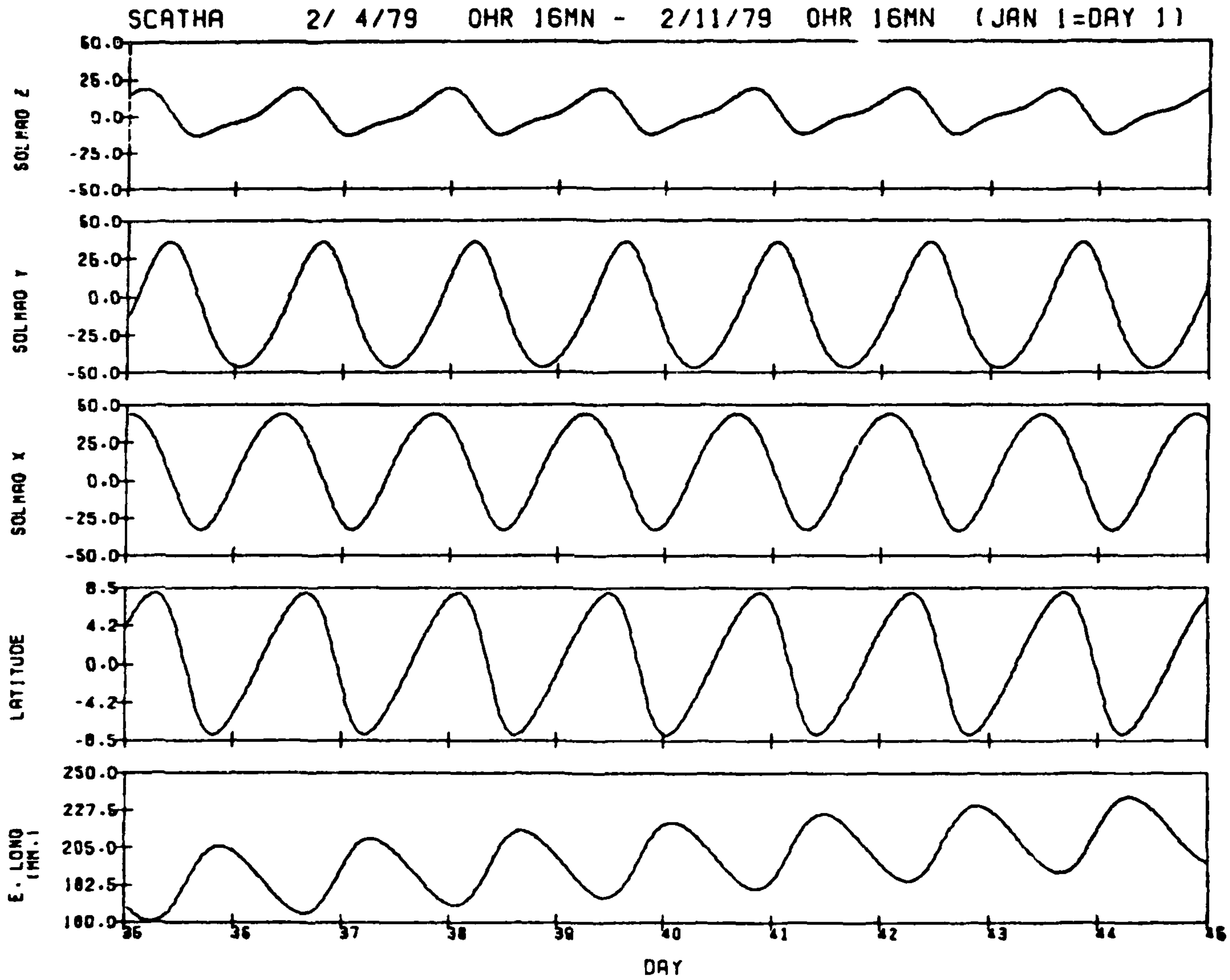

Figure 16. Display of Solar/Magnetospheric Coordinates for the SCATHA Satellite

2.2.4 Mathematical Method

The subroutine SOLMAG converts a set of ECI coordinates and associated universal time to geocentric solar magnetospheric coordinates. The transformation is based upon four quantities: Greenwich sidereal time, solar right ascension and declination, and the orientation of the Earth's magnetic north pole.

Greenwich sidereal time is calculated using an algorithm for ephemeris sidereal time from Reference (3). The time is then converted from the ephemeris meridian to the Greenwich meridian by a linear transformation. The solar right ascension and declination are calculated by means of routines given in References (3) and (4).

These parameters are combined with the position of the Earth's magnetic north pole in the following set of vector equations defining solar magnetospheric coordinates (AX, AY, AZ).

Let THET and PHI define the latitude and longitude of geomagnetic north pole and GST be Greenwich sidereal time. Then the Earth centered inertial coordinates (ECI) of the unit vector having the orientation of the geomagnetic north pole are

$$\bar{D} = \begin{pmatrix} DX \\ DY \\ DZ \end{pmatrix} = \begin{pmatrix} \mathrm{COS(THET)}\ \ \mathrm{COS\ (GST + PHI)} \\ \mathrm{COS(THET)}\ \ \mathrm{SIN\ (GST + PHI)} \\ \mathrm{SIN(THET)} \end{pmatrix}$$

Also, let the position of the Sun's declination and right ascension be DECS and RAS. Then the ECI coordinates of the unit vector oriented in the direction of the Sun is

$$\bar{S} = \begin{pmatrix} SX \\ SY \\ SZ \end{pmatrix} = \begin{pmatrix} \mathrm{COS(DECS)}\ \ \mathrm{COS(RAS)} \\ \mathrm{COS(DECS)}\ \ \mathrm{SIN(RAS)} \\ \mathrm{SIN(DECS)} \end{pmatrix}$$

Now define a vector $\bar{T} = \begin{pmatrix} TX \\ TY \\ TZ \end{pmatrix}$ as

$$\bar{T}^t = \bar{D}^t \times \bar{S}^t,$$

where $\bar{T}^t$ denotes the transpose of $\bar{T}$.

Also define $\bar{U}$ as

$$\bar{U}^t = \bar{S}^t \times \bar{T}^t.$$

Then if (AS, AT, AU) denotes ECI coordinates, the solar/magnetospheric coordinates are:

$$\begin{pmatrix} AX \\ AY \\ AZ \end{pmatrix} = \begin{pmatrix} SX & SY & SZ \\ TX & TY & TZ \\ UX & UY & UZ \end{pmatrix} \cdot \begin{pmatrix} AS \\ AT \\ AU \end{pmatrix}.$$

2.3 References

1. Minka, K, Fein, J. and Clemenz, B.E., "Orbit Determination and Ephemeris Computation," AFCRL Report No. 66-259, May 1966.

2. King-Hele, D., "Theory of Satellite Orbits in an Atmosphere," Butterworths London, 1964.

3. Williams, Jr., W. "Prediction and Analysis of Solar Eclipse Circumstances," AFCRL Report No. 71-0049, March 1971.

4. Russell, C. T., "Geophysical Coordinate Transformations," Cosmic Electrodynamics, 2, pp 184-196, 1971.

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3.0 Ionospheric Research Support

In the early history of ionospheric research, observations were generally limited to those made from fixed ground stations. This restricted researchers' ability to track specific moving features with passing time and to view structures from different aspects. Today, satellites and instrumented aircraft constitute moving platforms which are used to enable researchers to perform a broader range of experiments. Time correlated observations are made simultaneously from multiple observing platforms. In planning for these experiments, and analyzing the data, it becomes necessary to evaluate a variety of viewing geometries, especially as they change with time. Two programs, SKY and IONTRK, have been developed to satisfy this type of requirement.

3.1 Program SKY

3.1.1 Introduction

A very fruitful technique of experimental ionospheric research is the recording of optical radiation associated with ionization present in the upper atmosphere. Optical systems are employed that provide 360° of azimuthal coverage together with broad elevation coverage that extends downward from the zenith.

Program SKY was written to display, in plot format, specific contours within the field of view of an observer using an "all-sky" camera or TV system. The camera, mounted upon an aircraft, takes a series of photographs of the sky covering 360° of azimuth. The computed plots are superimposed upon these photographs to indicate, as benchmarks, the relative locations and motions of optical features appearing within the field of view of the optical system.

Specifically, geographic or geomagnetic latitude and longitude contours at particular altitudes are plotted from a particular aircraft position. There is also the capability to plot specified isolated points in space.

Much of the program is devoted to making available the various input options. Among these are:

1) Isolated points or entire contours can be plotted.

2) Contours of constant geographic or geomagnetic latitude or longitude can be specified.

3) Aircraft position can be determined from standard flight track cards. Plots are produced every ten minutes. Typically, two latitude and two longitude contours are projected onto the field of view.

4) Aircraft position can also be determined from a physical tape obtained from the aircraft's inertial navigation system. The program operation in this case is the same as 3) above.

5) Manual input is available in which aircraft position and contours or points are input directly to the program.

3.1.2 *Program Function and Organization*

The geometry of the problem to be solved is shown in Figure 1. Table 1 lists the major functions which must be performed by SKY. The contours to be plotted could be, for example, a particular geographic or geomagnetic meridian at a given altitude. If the specification is in terms of geographic coordinates, one immediately has the points to be displayed represented by their latitude, longitude, and altitude. If the specification is for magnetic contours the points of interest must be converted to the geographic system. Subroutine CORRGM2 performs this function.

Next, subroutine AZEL is used to transform geographic coordinates to equivalent azimuth and elevation referenced to the aircraft's location. An instrument function is then applied to transform azimuth and elevation to the coordinates of the display of the particular device being used (all-sky camera or TV camera). Account is taken of the heading of the aircraft to insure that azimuth is correctly referenced to the direction of north. Table 1 summarizes the key functions performed by SKY.

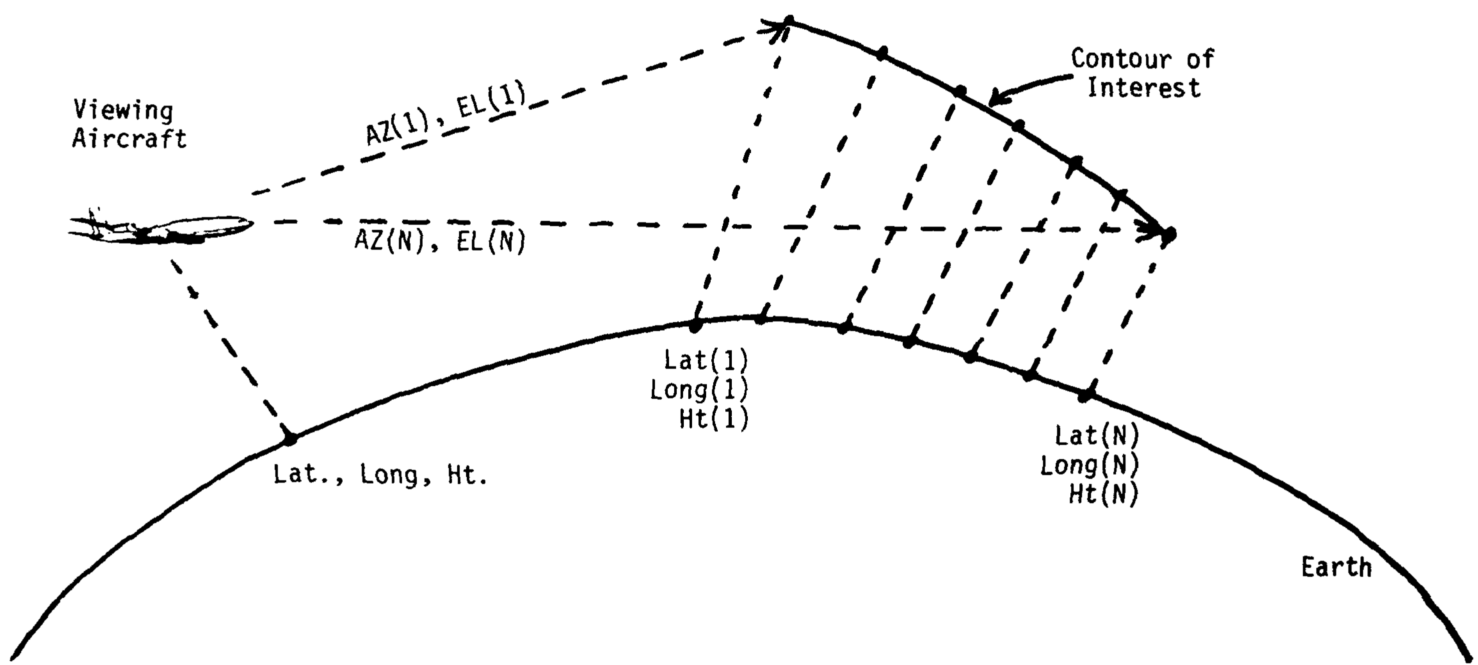

Figure 1. Viewing Geometry for Sky

- Input of A/C position/time history and specification of coordinates to be displayed.

- Conversion of geomagnetic coordinates (if necessary) to geographic

- Conversion of geographic coordinates of points to be plotted to azimuth/elevation referenced to aircraft location

- Plotting of overlays

Table 1. Principal Functions Performed by SKY

The preceding operations are performed for a given instant of time, for which the location (latitude, longitude, altitude) of the aircraft is known. The output is a plotted overlay. Time is then incremented, yielding a new aircracft location. The process is repeated, producing another overlay. When the aircraft track is defined by standard flight cards, subroutines FLTRANS and CORFL, modified versions of similar routines used in Program LOKANGL, process the flight card information to yield latitude and longitude at the desired equi-spaced time intervals. These routines interpolate aircraft geographic positions for times/locations intermediate to those specified on successive flight cards.

Figure 2 illustrates the flow of information in Program SKY as the foregoing operations are implemented. To minimize core memory requirements, the program is organized into five overlays. Communication between overlays is by means of labelled common blocks and files TAPE3 and TAPE4. The files contain points to be plotted. The labelled common contains input and option selection data. The division of functions among the overlays is shown in Figure 2, where dashed outlines are used indicate individual overlays.

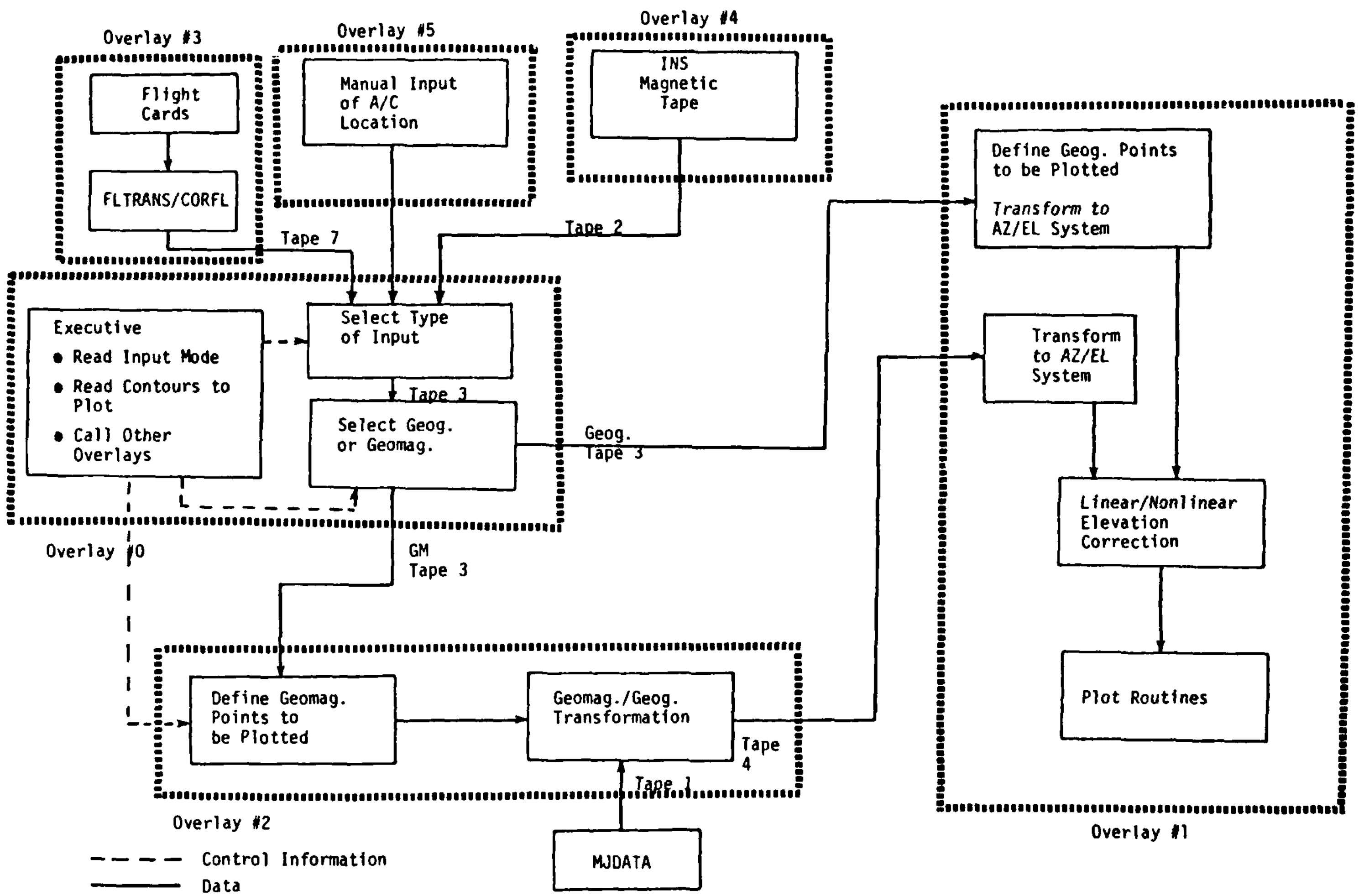

Figure 2. Information Flow Diagram for SKY

3.1.3 Mathematical Procedures

SKY requires the transformation between the coordinates of a point in space and its image in the all-sky camera photograph. Subroutine AZEL calculates the azimuth and elevation of an observation point from a given aircraft position. The subroutine uses the following method to calculate elevation, EL, and azimuth, AZ.

Let

$$X = (X_1, X_2, X_3) \text{ be aircraft position}$$

and

$$Y = (Y_1, Y_2, Y_3) \text{ be observation point}$$

relative to geocentric orthogonal rectangular coordinate system.

The elevation is calculated as:

$$EL = \frac{\Pi}{2} - \text{ARC COS} \left\{ \frac{\bar{X} \cdot \bar{Y}}{|\bar{X}| \times |\bar{Y}|} \right\}$$

The azimuth is calculated as follows:

Let

$$\bar{N} = (0,0,1) \text{ be unit north polar vector.}$$

and

$$\bar{E} = \frac{\bar{N} \times \bar{X}}{|\bar{X}|} = \frac{(-X_2, X_1, 0)}{|\bar{X}|} \text{ be eastward directed unit vector}$$

Then the local north is:

$$\overline{LN} = \frac{\overline{E} \times \overline{X}}{|\overline{X}|}$$

The azimuth can be calculated as:

$$AZ = \text{ARC TAN} \left\{ \frac{(\overline{Y} - \overline{X}) \cdot \overline{E}}{(\overline{Y} - \overline{X}) \cdot \overline{LN}} \right\}$$

3.1.4 Input

Input of choice of options is by means of cards. Aircraft navigation information can be furnished either by means of flight cards or by a physical tape; the instrument navigation system (INS) tape. The set-up of input cards is shown in Table 2.

Card No.	Variable Name	Format	Variable Description
1	IOPT	5I1	Option Parameter Array
2	RADIUS	F10.2	Plot Radius
	XMINEL	F10.2	Horizon Elev Angle
	XIONHEI	F10.2	Observation Height

THESE CARDS ARE FOR MANUAL MODE OF OPERATION.

3	LMON	I2,1X	Month
	LDAY	I2,1X	Day
	LYR	I4,1X	Year
	LHR	I2,1X	Hour
	LMIN	I2,1X	Minute
	LSEC	I2	Seconds
4	ACLAT	F10.2	A/C Latitude
	ACLON	F10.2	A/C Longitude
	ALT	F10.2	A/C Altitude
	ARHEAD	F10.2	A/C Heading
5	I	I1,9X	No. of Contours
	PLLAT	6F10.2	Latitude of Contours
6	J	I1,9X	No. of Contours
	PILLON	6F10.2	Longitude of Contours

Repeat cards 3 to 6 for each successive overlay ending program with LMON=99 on card 3.

For A/C position from cards (IOPT(1)=2) insert flight track cards after card 2 ending with =1000.

IOPT is an option parameter array controlling program execution.

IOPT(1)	1	A/C Position Taken from TAPE2
	2	A/C Position Taken from Flight Cards
IOPT(2)	1	Geographic Coordinates Plotted
	2	Geomagnetic Coordinates Plotted
IOPT(3)	1	TV Camera Lens (linear)
	2	All Sky Camera Lens (nonlinear)
IOPT(4)	1	Latitude and/or Longitude Contours Plotted
	2	Isolated Points are to be Plotted
IOPT(5)	2	Manual Mode of Operation

Table 2. Input Cards for SKY

3.1.5 Output

The chief output of Program SKY is a series of plots, drawn to the same scale as the photographic images with which they are to be used as overlays. A typical example is shown in Figure 3. Within the circular frame are the contours which are intended to be combined, as an overlay, with a photograph from the "all-sky" optical system. The zenith maps into the point at the center of the circle; and radial distance from this point corresponds to zenith angle. Registration for azimuth angle is provided by the labelled axes.

A printout is provided that tabulates the track of the aircraft. As an error check, the desired input options should be checked against those echoed at the top of the printout.

3.1.6 Program Restrictions and Timing

Grids larger than 5.0 inches will cause information to exceed the plotting dimension in the Y- direction. 200 inches of plot is the limit in the X-direction. If more is needed, divide the input into two smaller runs. Check input echo at top of output to see if this matches the user's intentions.

SKY requires 110000 octal core memory. A typical time allocation is 100 seconds. Control card set-up for a typical run is shown in Table 3.

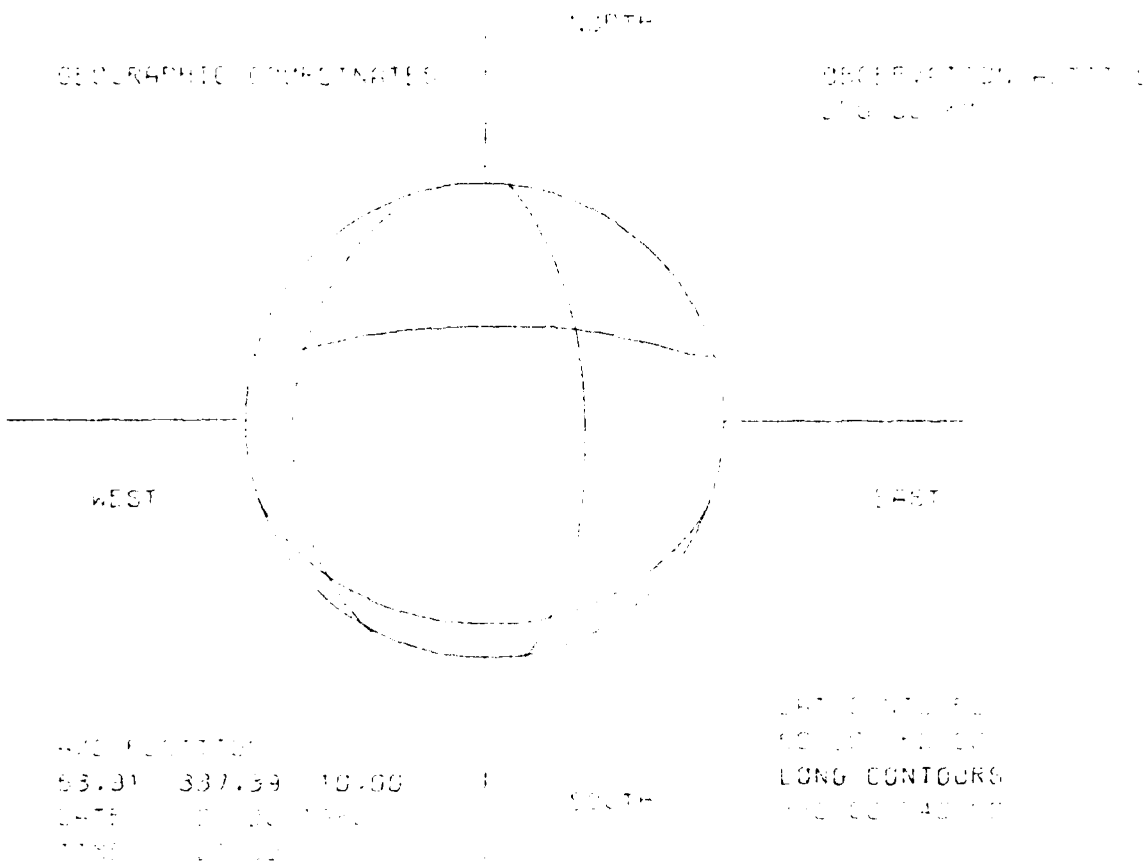

Figure 3. Typical Overlay Plot from Program SKY

```
LOBOB, T100, CM110000.          (Job card)
REQUEST, PLOT, *Q.
ATTACH, PEN, ONLINE PEN.
LIBRARY, PEN.
ATTACH, TAPE1, MJDATA, ID = ROBERTS, MR=1.
LDSET, PRESET = ZERO.
LGO.
DISPOSE, PLOT, *PL.
7/8/9          (END OF RECORD)
[INPUT CARDS]
7/8/9          (END OF RECORD)
6/7/8/9        (END OF INFORMATION)
```

Table 3. Typical Control Card Sequence for SKY

3.2 IONTRK

3.2.1 Background

The complexity assumed by some ionospheric experiments is evident in the case in which two instrumented aircraft make simultaneous observations. The first forms one leg of a satellite-to-aircraft radio path. Interest centers in interactions of the radio wave with the ionosphere through which it passes. A standard function of Program LOKANGL is identification of the location of this interaction region in terms of the "sub-ionospheric coordinates". The second aircraft is to make observations of this interaction region. For purposes of experiment planning, and for subsequent data analysis, the experimenter needs to know the azimuth and elevation angles, at the second aircraft, of the ionospheric interaction region for the first aircraft. The geometry is depicted in Figure 4. The IONTRK version of LOKANGL was developed to satisfy this requirement. The reader may wish to refer to Section 2 for background information on LOKANGL.

3.2.2 Approach

Necessary input to the calculation is the evaluation of the subionospheric point associated with the first aircraft. To obtain this data, the program performs what is essentially a normal LOKANGL sequence of operations; however the output of subroutine WRSTP is written to file TAPE1.

Control then returns to the main routine, LOKANGL, as usual. It is at this point that the major modifications occur. Normally LOKANGL would proceed to terminate. This chain of commands is interrupted and the new calculations are inserted, as shown in Figure 5. FLTRANS is called to read and process data from a second set of flight cards which correspond to the track of the second aircraft. This information is written to TAPE2. TAPE1 is read, to make available within LOKANGL the data relating to aircraft one. CORFL is then called to read TAPE 2 and provide interpolated latitudes, longitudes, and times for aircraft two. At this point, the coordinates of both the viewing system and the region being viewed are defined for the specified instant of time. Calculation of the azimuth and elevation can now proceed. The results are then printed out and the program terminates.

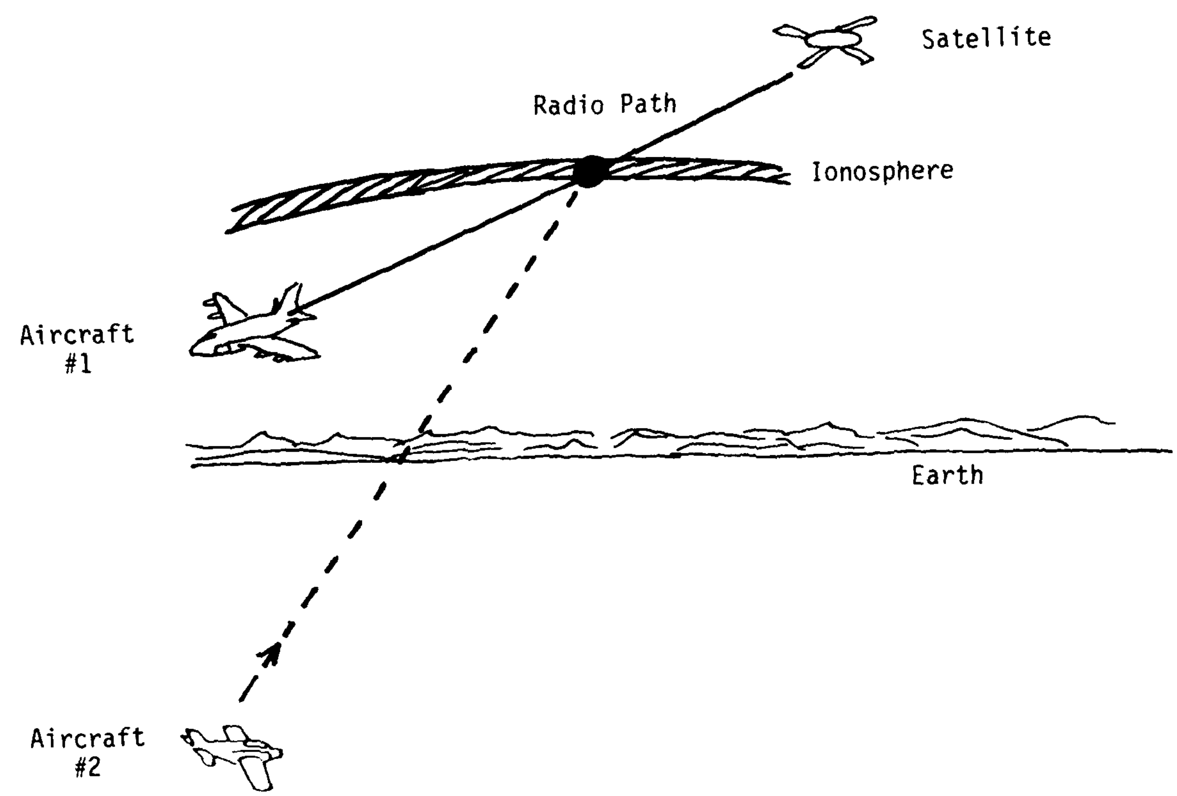

Figure 4. Path Geometry for Tracking Ionospheric Intersection

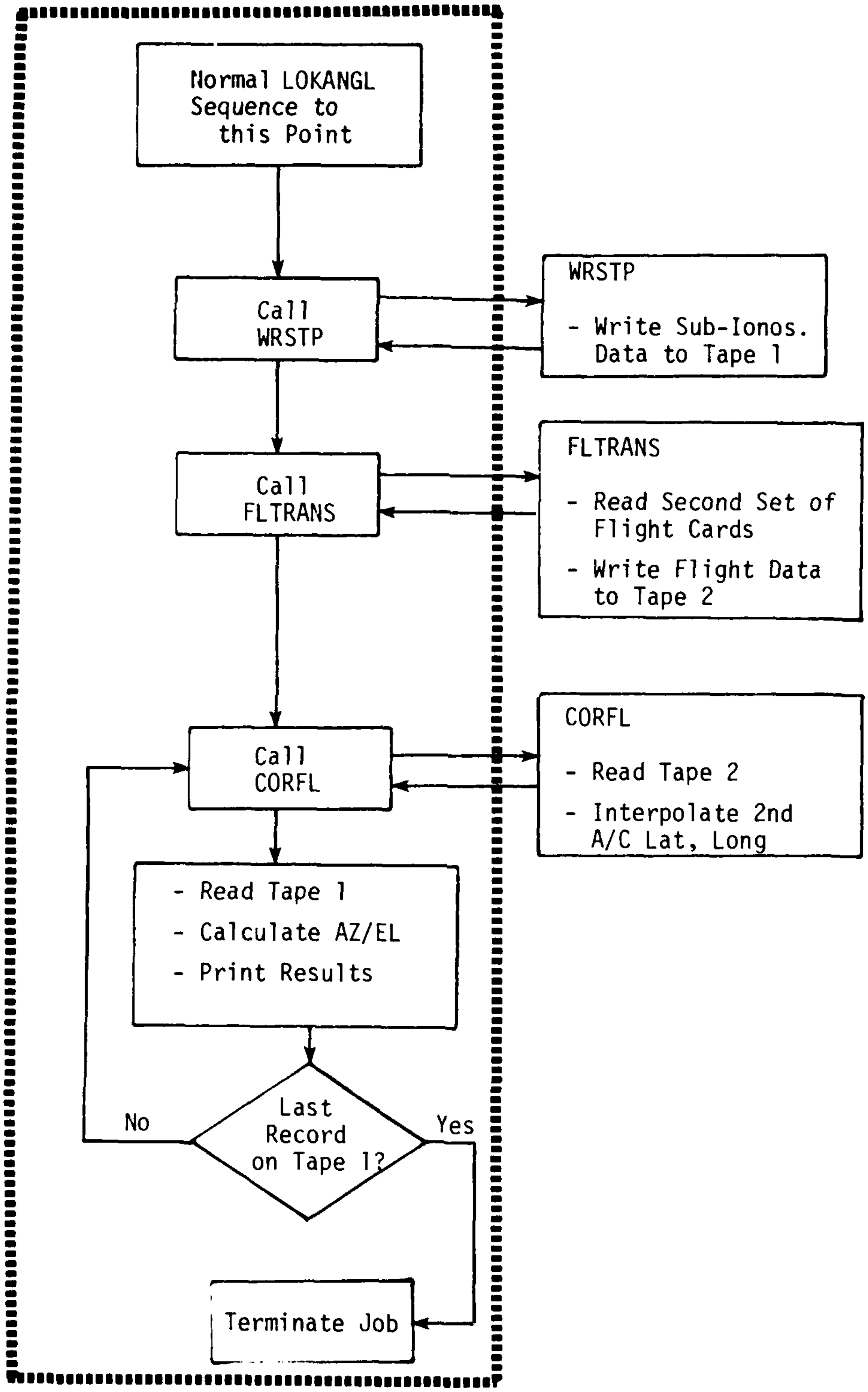

Figure 5. Flow Chart for Program IONTRK

3.2.3 Mathematical Method

The problem of evaluating the azimuth and elevation is that addressed by subroutine AZEL described in Section 3.1.3, to which the reader is referred.

3.2.4 Input/Output

The organization of the data deck for IONTRK, which is shown in Table 4, is basically similar to that for LOKANGL. The major differences are the following: a modification to card 3 to enter both the variable IONTRK, which selects the IONTRK mode; and the altitude of the second aircraft. In addition the card 7 series, which represents flight cards for the second aircraft, has been added.

A sample output is shown in Figure 6. The flight segment referred to in the first two columns is defined as that portion of the aircraft flight path intermediate between two successive flight cards. Segment number one, for example, falls between the points given on the first and second flight cards. Looking downward, azimuth is measured counterclockwise from north.

```
INPUT FORMAT
**************************************************************************
DATA DECK SETUP

CARD    COLS                   DESCRIPTION
1       1     CODE OF ORBITAL DETERMINATION FORM
              1=FORM NO. 3 \  SCF 2-CARD POS.-VEL. SET
              2=FORM NO. 2 \  ADC 2-CARD ELEMENT DATA SET
              3=3-CARD ELEMENT DATA SET
              4=OSCULATING ELEMENTS
              5=FORM NO.1\ ADC 5-CARD DATA SET

2+            ONE OR MORE ELEMENT SETS
        2-9   A OR U ON FIRST CARD OF ALL SUBSEQUENT ELEMENT SETS
        8     T INDICATES THRUST TIME CARD\ ONE CARD SET
              PROVIDES TIME OF THRUST IN STANDARD COLUMNS

3       1-3   NO. OF STATIONS ( NMS ).IF NO STATIONS USE 0
        32-46 ALTITUDE (M) SECOND AIRCRAFT FOR IONO. TRACK
              MODE  F15.1
              FOR AIRCRAFT FLIGHT SIMULATION RUN, USE -1
        6     CODE 1 OR 0 FOR PRINT CONTROL OF STATION DATA
              0=PRINT BY TIME ONLY
              1=PRINT BY STATIONS
        7-10  0=STANDARD
              IHIGHT=SUB-IONOSPHERIC ALTITUDE (KM)     I3
        11-15 MINELV=MIN ELEVATION FOR SAT VIEWING  I3
        16-30 FOR AIRCRAFT FLIGHT SIMULATION RUN, ALTITUDE OF
              AIRCRAFT (M) F15.1
        31    IONTRK:0=STANDARD:1=IONO. TRACK MODE FOR FLIGHT
              SIMULATION ( PROVIDED ALSO NMS=-1 )

3+            STATION LOCATION CARDS,IF NMS.GT.0
        1-5   NO. OF STATION (NUMBER)
        7-8   0=GEODETIC SYSTEM
        9-23  STATION GEODETIC LATITUDE, DEGREES
        24-38 STATION LONGITUDE (POSITIVE WEST), DEGREES
        39-53 STATION HEIGHT, METERS
        61-72 NAME OF STATION

4       1-15  TIME INCREMENT IN SECONDS. F15.5
        17-69 TIME INTERVAL FOR PRINT OR TAPE 2 WRITE
              START COLS\ 17-18:20-21:23-24:26-28:31-34:36-41
              FINAL COLS\ 43-44:46-47:49-50:52-55:57-60:62-67
              TIME         MONTH:  DAY: YEAR: HOUR:  MIN:  SEC
              FORMAT          I2:   I2:    I2: F3.1: F3.1: F5.3
              FINAL TIME NOT NECESSARY IF NMS.EQ.-1

5             AIRCRAFT POSITION-TIME CARDS, IF NMS.EQ.-1
5A            TITLE REQUIRED (4A10)
5+            TWO OR MORE POSITION-TIME CARDS
        1-5   HOURS FROM STARTING TIME I5
        6-10  MINUTES F5.1
        11-15 DEGREES LATITUDE I5
        16-20 MINUTES LATITUDE  I5
        21-25 DEGREES LONGITUDE I5
        26-30 MINUTES LONGITUDE I5
7       2-5   "1000" INDICATES END OF POSITION-TIME CARDS

6             CODE FOR PRINT-OUT  0= NO PRINT: 1= PRINT FOLLOWING\
        2     1=POSITION AND VELOCITY
        4     1=SUB-SATELLITE DATA
        6     1=OSCULATING ELEMENTS
        8     [illegible]
        9-10  [illegible]
              [illegible]
        11-1? [illegible]
7A+           [illegible]
              [illegible]
              [illegible]
7B      2-5   [illegible]

8             [illegible]

              [illegible]
[illegible]
**************************************************************************
```

Table 4. Organization of Data Deck for IONTRK

ALTITUDE A/C-1= 9999.M   ALTITUDE A/C-2=10000.M   ALT IONOSPHERE=300KM

A/C-1 SEG. NO.	A/C-2 SEG. NO.	MO DY YR	UNIVERSAL TIME HR	MIN	SEC	A/C-1 LOCATION LAT DEG	W.LONG DEG	A/C-2 LOCATION LAT DEG	W.LONG DEG	SUB IONO POINT LAT DEG	W.LONG DEG	TRACKING ANGLES AZIM. DEG	ELEV. DEG
1	1	3/21/79	0	5	0	30.00	75.00	30.00	69.00	28.50	74.03	-102.73	20.07
1	1	3/21/79	0	6	0	30.10	75.00	30.12	69.09	28.60	74.03	-104.73	23.34
1	1	3/21/79	0	7	0	30.20	75.00	30.23	69.39	28.69	74.03	-1[illegible].14	26.40
1	1	3/21/79	0	8	0	30.30	75.00	30.34	70.09	28.79	74.03	-110.12	29.71
1	1	3/21/79	0	9	0	30.40	75.00	30.45	70.79	28.88	74.03	-112.40	33.72
1	1	3/21/79	0	10	0	30.50	75.00	30.55	71.49	28.98	74.03	-114.[illegible]	[illegible]
1	1	3/21/79	0	11	0	30.60	75.00	30.65	72.[illegible]	29.07	74.03	[illegible]	43.70
1	1	3/21/79	0	12	0	30.70	75.00	30.74	72.59	29.16	74.07	[illegible]	49.42
1	1	3/21/79	0	13	0	[illegible]	[illegible]	30.63	73.59	29.26	74.03	-149.76	54.7[illegible]
1	1	3/21/79	0	14	0	30.90	75.00	30.92	74.29	29.35	74.03	-164.4[illegible]	59.31
1	1	3/21/79	0	15	0	31.00	75.00	31.00	75.00	29.45	74.03	165.05	66.37
1	1	3/21/79	0	16	0	30.93	74.93	[illegible]	74.[illegible]	29.38	74.56	171.78	61.02
2	2	3/21/79	0	17	0	30.87	74.87	30.6[illegible]	74.59	29.32	74.53	176.36	63.67
2	2	3/21/79	0	18	0	30.80	74.80	30.40	74.39	29.26	74.44	-177.[illegible]	66.25
2	2	3/21/79	0	19	0	30.73	74.73	30.20	74.19	29.20	74.3[illegible]	-170.61	68.65
2	2	3/21/79	0	20	0	30.67	74.66	30.00	73.99	29.14	74.32	-161.50	70.7[illegible]
2	2	3/21/79	0	21	0	30.60	74.60	29.80	73.79	29.08	74.25	-150.3[illegible]	72.30
2	2	3/21/79	0	22	0	30.53	74.53	29.60	73.59	29.02	74.1[illegible]	-137.46	73.16
2	2	3/21/79	0	23	0	30.47	74.46	29.40	73.39	28.96	74.13	-123.67	73.17
2	2	3/21/79	0	24	0	30.40	74.40	29.20	73.20	28.90	74.07	-110.49	72.32
2	2	3/21/79	0	25	0	30.33	74.33	29.00	73.00	28.84	74.01	-99.50	70.75
2	2	3/21/79	0	26	0	30.27	74.26	29.20	73.20	28.77	73.95	-122.32	73.19
2	2	3/21/79	0	27	0	30.20	74.20	29.40	73.40	28.71	73.89	-147.7[illegible]	72.70
2	2	3/21/79	0	28	0	30.13	74.13	29.60	73.60	28.65	73.82	-166.04	69.54
2	2	3/21/79	0	29	0	30.07	74.07	29.80	73.80	28.59	73.76	170.49	66.96
2	2	3/21/79	0	30	0	30.00	74.00	30.00	74.00	28.53	73.73	169.79	65.95

Figure 6. Sample Printout from Program IONTRK

4.0 SCATHA Support

4.1 Introduction

The electrical charging, both absolute and differential, of spacecraft in orbit has been found to have a potentially adverse effect on performance of satellite-borne systems. Among the objectives of the SCATHA experiments are the investigation of the charging process and methods for its control.

Important among natural phenomena affecting the charging process is the flow of photoelectron currents induced by incident solar ultraviolet radiation. An event having a dramatic effect on charging is suppression of illumination during eclipsing of a vehicle as it passes within the Earth's shadow. Another natural environmental factor affecting charging is the interaction between the vehicle and the dense, hot plasmas within which it may be imbedded during magnetospheric substorms. Thus, particle environments and solar illumination conditions are of importance in interpreting SCATHA experimental measurements.

The paths of energetic charged particles in the magnetosphere and upper ionosphere tend to be guided by the lines of the Earth's magnetic field, along which the particles spiral. (1,2) The field lines, then, provide conducting channels for the currents which these flowing particles create. In order to compare SCATHA observations with data from other sensors, it is of interest to identify time intervals when the SCATHA vehicle is magnetically coupled to ground stations and/or to other space vehicles of interest.

To fulfill this need, two software systems have been developed. The first, CONJ/FPLOT, traces the movement in the northern hemisphere of the magnetic footprint of SCATHA. The precise footprint of interest here is the one at ionospheric height, usually 100 km, where the highly conductive E-layer connects with the conducting path along the magnetic field lines.

The second system, FTPRNT, searches for periods when SCATHA and a second vehicle intersect a common field line. Under this condition, the particle environments of the two vehicles should be closely related. The third system, Program FOOT, evaluates solar illumination conditions at footprint locations.

The change in illumination conditions as SCATHA passes into and out of the Earth's shadow should correlate well with variation in vehicle potential at times when the vehicle is immersed in a dense plasma of high energy particles associated with magnetospheric substorms. To assess this relationship, calculations at several levels of precision were performed. Program PENUMB provides times of umbral and penumbral passage. LOKANGL, coupled with a special plotting package, ECPLT, provides summary plots of eclipse conditions during the two annual seasons: fall and spring.

The Air Weather Service has provided a variety of astro-geophysical background data to support SCATHA analyses. This information includes particle density distributions with respect to energy. These data come packed on tape prepared by a UNIVAC 1110 system. A program was developed to unpack this data and display it on microfiche plots.

4.2 Program CONJ/FPLOT

4.2.1 Objective

The CONJ/FPLOT system is intended to accept, as input, an ephemeris tape, in LOKANGL TAPE3 format, and to provide, as output, a plot of the time history of movement of the 100km footprint of the SCATHA satellite in the northern hemisphere. The plot, an overlay in polar form, uses as coordinates the corrected geomagnetic latitude and longitude. The scale should match that of an existing Northern polar projection map of the world, depicting continental outlines in corrected geomagnetic coordinates. The footprint plot is to be used as an overlay for this map, and includes appropriate registration marks at the center and along the prime magnetic meridian.

4.2.2 Approach

Depending on the overall time period to be covered and the time interval between successive ephemeris calculations, Program CONJ accepts either one or two ephemeris files (TAPE 2, TAPE 3). Figure 1 shows the flow of operations. Subroutine MGFLD2 is called to perform the field line tracing. (Actually, this function is performed by LINTRA, a subroutine in the MGFLD2 package.)

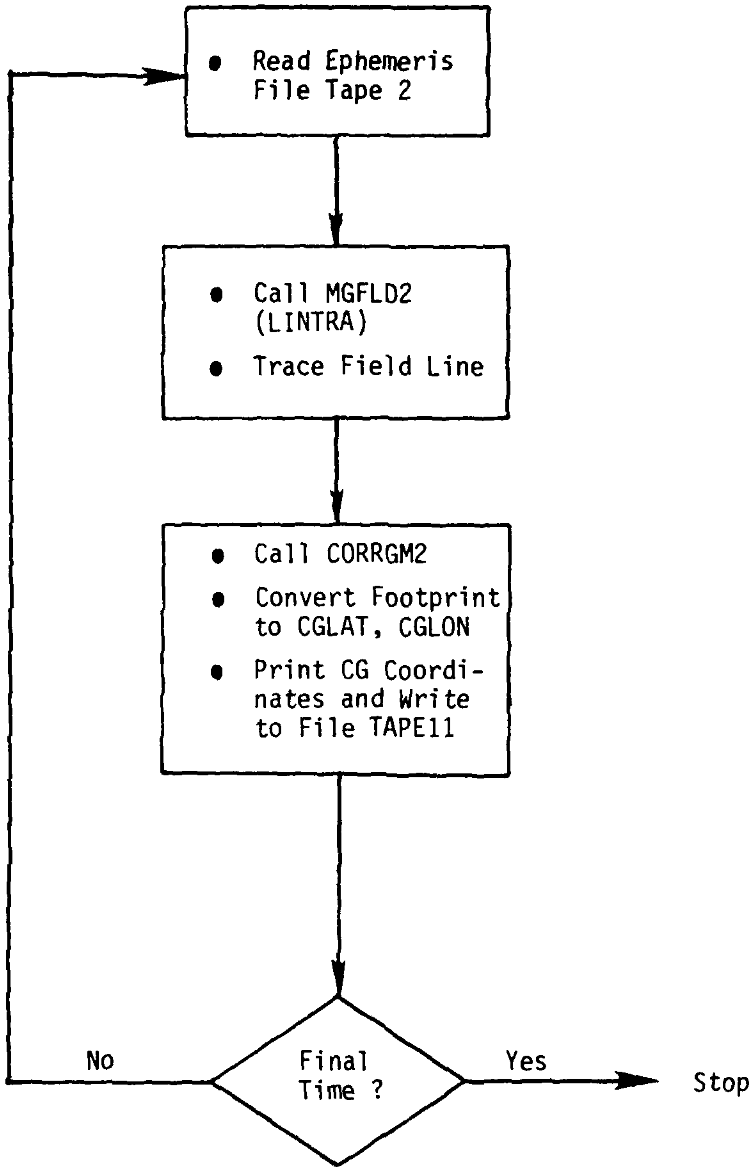

Figure 1. Operational Flow for Program CONJ

The line is traced both up and down the field line from the vehicle's location. It is not obvious, a priori, which will yield the footprint in the northern hemisphere. When the geographic coordinates of the footprint have been determined, subroutine CORRGM2 is called to perform transformation to corrected geomagnetic coordinates. The results are printed in tabular form and written to file TAPE11.

A continuous plot of footprints has been found to be too complex to be useful, as data for successive days overlap extensively. This problem has been avoided by presenting footprints plotted only for a selected day of the week (e.g. for all Mondays, but only Mondays, within the overall time period of interest.)

The second phase of the operation involves excercising program FPLOT to read file TAPE11 and plot the resulting points. CONJ/FPLOT are run sequentially in one pass, linked together by job control cards.

4.2.3 Input/Output

The set-up of input cards for CONJ is shown in Table 1. Typical printed output is shown in Figure 2. Input and output files for CONJ are listed in Table 2.

Input cards for FPLOT are described in Table 3. FPLOT produces a summary listing, shown in Table 4, which echoes the specified input conditions and summarizes key plotting data for each successive day plotted.

Figure 3 is an example of the plot which is the final product. Notice that each hour is marked by a dot and the latest time plotted for given day is denoted by a dot within a circle. The earliest time is referenced to the first digit of the day of the month of the date.

Card No.	Variable	Columns	Format	Description
1	NMON	1-5	I5	Beginning Month
	NDAY	5-10	I5	Beginning Day
	NYR	11-15	I5	Beginning Year
	MYDAY	16-20	I5	Corresponding Weekday No. Where 1 = MON. through 7 = SUN. (0<MYDAY<8)
	HALT	21-30	F10.0	Geodetic Altitude of Conjugate Intersection
2	COEF	1-20	2A10	Coefficient File Label
	TM	21-30	F10.2	Update Year for Coef. File (19xx.xx)

Table 1. Format of Input Cards for Program CONJ

COEFFICIENT SET USED IGRF(1975) UPDATED TO 1979.00

DATE			U TIME		SATELLITE			FOOTPRINT			
MO	DY	YR	HR	MN	GC LAT	E LONG	ALT(KM)	GD LAT	E LONG	GM LAT	E LONG
7	16	79	0	2	-4.075	301.754	40253.696	55.862	292.509	67.820	11.72
7	16	79	0	12	-3.853	301.230	40524.075	55.937	292.153	67.894	10.137
7	16	79	0	22	-3.629	300.695	40757.044	55.943	291.832	67.968	9.631
7	16	79	0	32	[illegible]	[illegible]	[illegible]	[illegible]	291.437	[illegible]	[illegible]
7	16	79	0	42	-3.174	299.536	41137.650	56.023	291.065	68.112	8.489
7	16	79	0	52	-2.944	[illegible]	[illegible]	[illegible]	290.689	68.185	[illegible]
7	16	79	1	2	-2.713	298.317	41539.413	56.094	290.305	68.259	7.306
7	16	79	1	12	-2.481	[illegible]	[illegible]	56.139	289.917	68.332	6.694
7	16	79	1	22	-2.248	297.136	41948.223	56.165	289.518	68.395	6.04
7	16	79	1	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	16	79	1	42	-1.780	295.751	42262.142	56.137	288.633	68.490	4.587
7	16	79	1	52	-1.545	[illegible]	[illegible]	[illegible]	[illegible]	68.536	[illegible]
7	16	79	2	2	-1.310	294.306	42573.357	56.215	287.745	68.581	3.125
7	16	79	2	12	-1.075	293.614	42657.673	56.227	287.233	68.626	[illegible]
7	16	79	2	22	-.840	292.910	42759.308	56.237	286.833	68.671	1.603
7	16	79	2	32	[illegible]	[illegible]	[illegible]	56.247	[illegible]	68.715	[illegible]
7	16	79	2	42	-.371	291.448	42957.379	56.257	285.924	68.760	.067
7	16	79	2	52	-.137	290.712	[illegible]	56.267	[illegible]	68.805	359.326
7	16	79	3	2	.097	289.972	43113.136	56.275	285.005	68.850	358.56
7	16	79	3	12	.330	289.227	[illegible]	56.289	284.545	[illegible]	357.789
7	16	79	3	22	.562	288.478	43265.421	56.301	284.084	68.891	357.014
7	16	79	3	32	.793	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	16	79	3	42	1.023	286.973	43263.659	56.327	283.164	68.931	355.467
7	16	79	3	52	1.252	[illegible]	[illegible]	[illegible]	282.704	68.952	[illegible]
7	16	79	4	2	1.480	285.465	43275.411	56.343	282.231	68.964	353.887
7	16	79	4	12	1.705	[illegible]	[illegible]	56.339	[illegible]	68.973	353.079
7	16	79	4	22	1.931	283.959	43243.318	56.334	281.273	68.975	352.26
7	16	79	4	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	16	79	4	42	2.376	282.481	43177.749	56.324	280.325	68.985	350.65
7	16	79	4	52	[illegible]	[illegible]	[illegible]	56.319	279.856	[illegible]	[illegible]
7	16	79	5	2	2.814	281.040	43059.733	56.313	279.390	68.959	349.08
7	16	79	5	12	3.029	[illegible]	[illegible]	[illegible]	278.927	[illegible]	[illegible]
7	16	79	5	22	3.243	279.521	42899.278	56.299	278.469	68.915	347.53
7	16	79	5	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	16	79	5	42	3.656	278.062	42644.667	56.293	277.569	68.864	346.00
7	16	79	5	52	[illegible]	[illegible]	[illegible]	56.277	277.126	[illegible]	345.25
7	16	79	6	2	4.072	276.699	42449.369	56.263	276.687	68.813	344.52
7	16	79	6	12	4.273	[illegible]	[illegible]	[illegible]	276.255	68.785	343.79
7	16	79	6	22	4.470	275.349	42162.951	56.237	275.832	68.757	343.08
7	16	79	6	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	68.727	[illegible]
7	16	79	6	42	4.853	274.071	41830.116	56.208	275.005	68.695	341.69
7	16	79	6	52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	68.665	[illegible]
7	16	79	7	2	5.222	272.811	41457.658	56.167	274.213	68.595	340.37
7	16	79	7	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	68.563	[illegible]
7	16	79	7	22	5.574	271.636	41049.630	56.117	273.454	68.485	339.12
7	16	79	7	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	16	79	7	42	5.905	271.589	40631.163	56.056	272.746	68.373	337.94
7	16	79	7	52	[illegible]	[illegible]	[illegible]	56.021	[illegible]	[illegible]	[illegible]
7	16	79	8	2	6.217	269.504	40113.641	55.982	272.031	68.249	336.357
7	16	79	8	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	16	79	8	22	[illegible]	268.611	[illegible]	55.892	271.471	68.115	335.85
7	16	79	8	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	16	79	8	42	6.763	267.779	39041.634	55.794	270.921	67.968	334.962
7	16	79	8	52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	334.567

Figure 2. Printout of Location of Footprint of Satellite in Geographic and Corrected Geomagnetic Coordinates

- o TAPE 1 IGRF75 magnetic field coefficients used by MGFLD 2.
- o TAPE 2 Vehicle ephemeris file in LOKANGL TAPE3 format.
- o TAPE 3 Additional ephemeris file, if required; sequential with TAPE2.
- o TAPE 10 Corrected geomagnetic field coefficients used by CORRGM2; Gustafsson or Hakura
- o TAPE 11 Output file, CGLAT and CGLON of footprints.

Table 2. Files used in Program CONJ

Card No.	Variable	Format	Description
1	ADAY (1-16)	16F5.0	Day of Month Values for Weekday (MYDAY)
2	MON (1-8)	8A10	Months Corresponding to ADAY (Left Justified)

Table 3. Format of Input Cards for Program FPLOT

```
JULY    AUGUST    SEPTEMBER
PLOT OF [illegible]

SMLAT AND SMLONS = [illegible]
BEGINNING XX AND YY = [illegible]
SMLAT AND SMLONS = [illegible]
ENDING XX AND YY = 6.457 [illegible] 1.[illegible]470352489
FULL DAY OF FOOTPRINTS PLOTTED, NUMBER OF POINTS = 144

SMLAT AND SMLONS = [illegible]
BEGINNING XX AND YY = 7.[illegible]322[illegible]64453 1.[illegible]95223972489
SMLAT AND SMLONS = [illegible]
ENDING XX AND YY = 8.[illegible]744[illegible]071244 2.[illegible]5679.91971
FULL DAY OF FOOTPRINTS PLOTTED, NUMBER OF POINTS = 144

SMLAT AND SMLONS = [illegible]
BEGINNING XX AND YY = 9.[illegible]571627514 3.214[illegible]25[illegible]5441
SMLAT AND SMLONS = [illegible]
ENDING XX AND YY = 9.2[illegible]5[illegible]14790431 3.4[illegible]15152714
FULL DAY OF FOOTPRINTS PLOTTED, NUMBER OF POINTS = 144

SMLAT AND SMLONS = [illegible]
BEGINNING XX AND YY = 9.[illegible]7.423[illegible]983 5.[illegible]4935
SMLAT AND SMLONS = [illegible]
ENDING XX AND YY = 9.923[illegible] 5.3[illegible]8665[illegible]4
FULL DAY OF FOOTPRINTS PLOTTED, NUMBER OF POINTS = 144

SMLAT AND SMLONS = [illegible]
BEGINNING XX AND YY = 9.[illegible]6471[illegible] 7.58[illegible]6281
SMLAT AND SMLONS = [illegible]
ENDING XX AND YY = [illegible].626[illegible]72[illegible]614 7.[illegible]24736
FULL DAY OF FOOTPRINTS PLOTTED, NUMBER OF POINTS = 144

SMLAT AND SMLONS = [illegible]
BEGINNING XX AND YY = 7.[illegible] 1.[illegible]7702
SMLAT AND SMLONS = [illegible]
ENDING XX AND YY = [illegible].548 [illegible] [illegible]
FULL DAY OF FOOTPRINTS PLOTTED, NUMBER OF POINTS = 144

SMLAT AND SMLONS = [illegible]
BEGINNING XX AND YY = [illegible]
SMLAT AND SMLONS = [illegible]
ENDING XX AND YY = 1.[illegible]7.[illegible] [illegible].277[illegible]
FULL DAY OF FOOTPRINTS PLOTTED, NUMBER OF POINTS = 144

SMLAT AND SMLONS = [illegible]
BEGINNING XX AND YY = .1.[illegible]475[illegible]1[illegible]15 5.7[illegible]64738
SMLAT AND SMLONS = [illegible]
ENDING XX AND YY = .1312[illegible]33332845 5.2[illegible]2[illegible]735917
FULL DAY OF FOOTPRINTS PLOTTED, NUMBER OF POINTS = 144

SMLAT AND SMLONS = [illegible]
BEGINNING XX AND YY = 1.[illegible]329[illegible]756751 2.9[illegible]153168165
SMLAT AND SMLONS = [illegible]
ENDING XX AND YY = 1.318427674048 2.[illegible]1375621.2
FULL DAY OF FOOTPRINTS PLOTTED, NUMBER OF POINTS = 144

SMLAT AND SMLONS = [illegible]
BEGINNING XX AND YY = 2.7[illegible] 1.6[illegible]316517477
SMLAT AND SMLONS = [illegible]
ENDING XX AND YY = 7.[illegible]525[illegible]68[illegible] 1.[illegible]7164[illegible]67.9
FULL DAY OF FOOTPRINTS PLOTTED, NUMBER OF POINTS = 144
```

Table 4. Summary Listing of Plotting Information from Program FPLOT

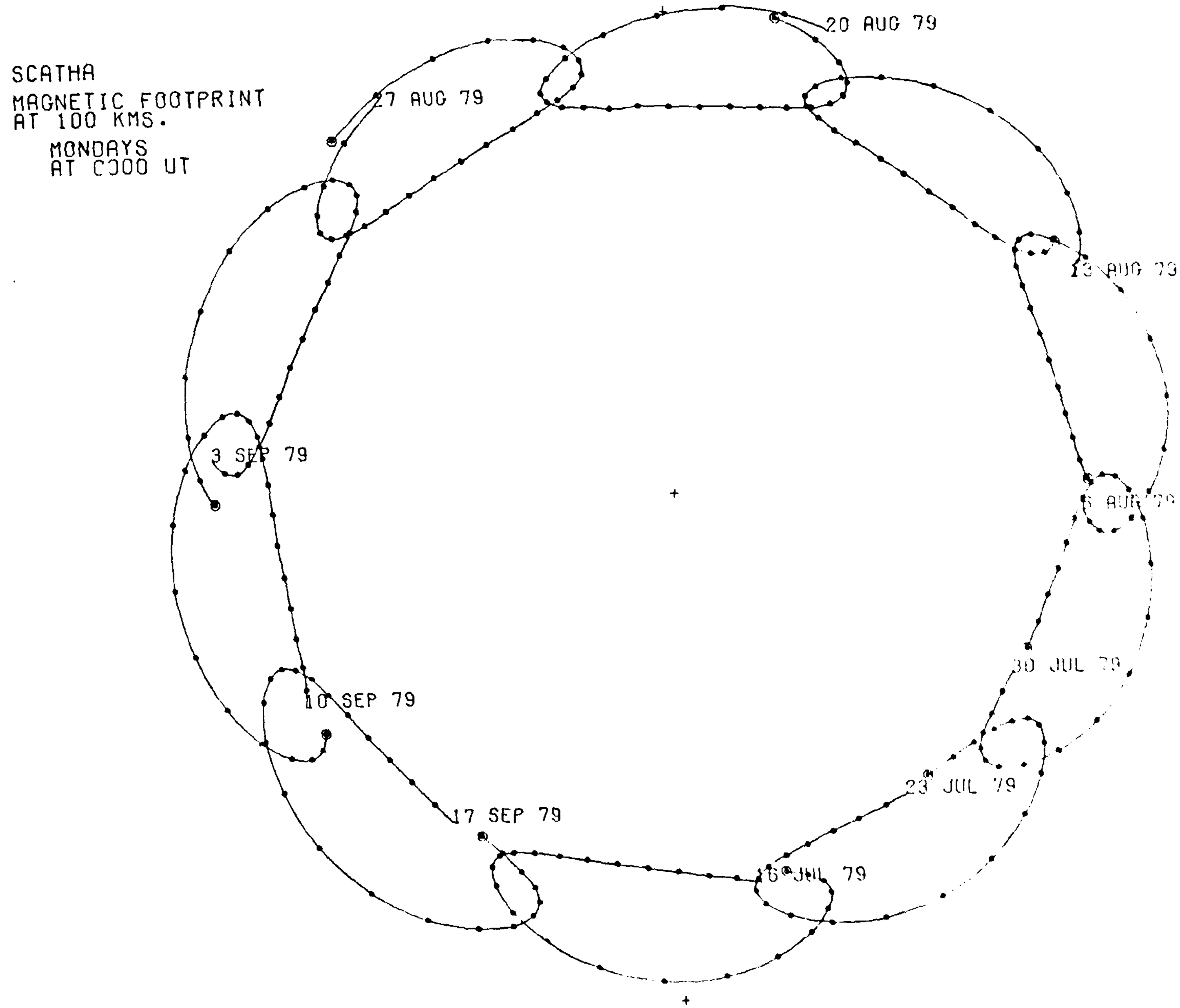

Figure 3. Three-Month History of Movement of SCATHA Footprint Plotted for Mondays

4.2.4 Control Cards and System Requirements

The following is the sequence of control cards used to run CONJ and FPLOT sequentially in a single pass.

```
LPOL, T300, CM130000.
REQUEST, TAPE11, *PF.
FTN, SL, R=3.
ATTACH, TAPE1, IGRF75X342L, ID=LOGBUC, MR=1.
ATTACH, TAPE2, SCAJUL10AUG13, ID=LOLEW, CY=1, MR=1.
ATTACH, TAPE3, SCAAUG15SEP19, ID=LOLEW, CY=1, MR=1.
ATTACH, TAPE10, MJDATA, ID=LOGICON, MR = 1.
ATTACH, XX, IORLIB, ID = LOGICON, MR = 1.
LIBRARY, XX.
LDSET, PRESET=ZERO.
LGO.
REWIND, TAPE11.
RETURN,LGO.
FTN, SL, R = 3.
REQUEST. PLOT, *Q.
ROUTE, PLOT, DC = PL, DEF.
ATTACH, PEN, ONLINEPEN.
LIBRARY, PEN.
LDSET, PRESET=ZERO.
LGO.
```

A typical CONJ/FPLOT run consumes 300 seconds of central processor time and requires 130K octal core memory.

4.3 Program FTPRNT

4.3.1 Objective

FTPRNT is a program which has been developed to identify time periods during which the SCATHA vehicle, in its near-synchronous altitude orbit, and DMSP F2, in its much lower altitude orbit, intersect, within a suitable tolerance, a common line of the Earth's magnetic field.

4.3.2 Approach

A significant feature of the problem is the disparity in altitudes, and hence orbital periods, between the two vehicles. This causes an asymmetry between the handling of the vehicles in the program. Conjugate footprints are traced from the location of the higher altitude vehicle down to the altitude of the lower altitude vehicle at that time. Thus, the two footprints and the lower altitude vehicle lie on a common spherical shell. The quality of "closeness" of the two field lines intersecting the satellites is quantified in terms of the spatial separation on this shell of the SCATHA footprints and the position of the lower satellite. Intersection is defined to occur whenever the vehicle - footprint separation in the shell subtends an angle at the center of the Earth which is less than five degrees in magnitude.

4.3.3 Functional Description

The program is divided into two major parts. A driver program FTPRNT reads two time-coincident ephemerides files created by LOKANGL in the TAPE3 format. It then calls MGFLD2 to calculate the coordinates of the conjugate footprints of SCATHA at the altitude of the lower satellite.

Next, a subroutine, SEARCH, is called at successive instants of time to identify when the lower satellite passes within 5° of either of the SCATHA conjugate footprints. In order to interpolate the ephemeris and simplify the analysis, it is assumed that the conjugate footprints of SCATHA move slowly with respect to the motion of the DMSP F2 satellite and that the altitude of DMSP F2 does not change appreciably over a span of six time intervals within the ephemeris. These assumptions can be satisfied by choosing a time increment for the DMSP F2 ephemeris that is sufficiently small (say, 3-10 minutes).

4.3.4 Mathematical Method

Subroutine SEARCH performs the principal analysis within FTPRNT. It identifies times and positions when two satellites intersect a common magnetic field line. The routine is used within the driver routine which reads two time-coincident ephemerides tapes. The higher altitude satellite is placed on file TAPE2; the lower, on TAPE3. The routine MGFLD2 is called to determine the position of the two conjugate points of the higher altitude satellite traced along the field line to the altitude of the lower altitude satellite. This information is passed to the subroutine SEARCH which then determines if the lower altitude vehicle passes within five degrees, measured from Earth's center, of either of the conjugate point positions. Such events, when identified, are printed by subroutine SEARCH.

The routine tabulates distances between conjugate points and the lower altitude satellite searching for minimum arc distance. When a minimum is found a check is made to determine if this distance is below a preassigned tolerance. If this condition is satisfied, a calculation is made to interpolate the actual minimum between the tabulated values.

Here two assumptions are made concerning the relationship between the two satellites. First, it is assumed that the conjugate point moves slowly with respect to the lower altitude satellite. In fact, it is assumed that the conjugate point remains stationary over three consecutive times of calculation centered at the tabulated minimum. Second, it is assumed that over a space of three consecutive times the positions of the lower altitude satellite are located on an earth centered sphere of radius the same as the tabulated minimum.

These assumptions simplify the analysis considerably and are reasonable for many vehicles provided the time interval between tabulated positions is chosen sufficiently small.

The problem, which is illustrated in Figure 4, can now be solved by means of spherical trigonometry. The appropriate equations, derived for the pair of right spherical triangles, are:

$$\cos(A) = \cos(ARCF)\ \cos(ARCMIN)$$
$$\cos(B) = \cos(E-ARCF)\ \cos(ARCMIN),$$

which can be combined as,

$$\tan(ARCF) = \left\{ \frac{\dfrac{\cos B}{\cos A} - \cos E}{\sin E} \right\} .$$

Also, the minimum arc, ARCMIN, can be expressed as,

$$\cos(ARCMIN) = \frac{\cos A}{\cos ARCF} .$$

Now an interpolation can be made to determine the actual position and time of the minimum, as well as the position and time when the lower altitude satellite passes within five degrees of the conjugate point.

4.3.5 Input/Output

Input for FTPRNT consists of punched cards and two data files. The cards required and their format are shown in Table 5. The two files, typically permanent files, are the ephemerides for the high and low altitude satellites, e.g., SCATHA and DMSP F2. These are in the standard LOKANGL TAPE3 format.

A sample output listing is shown in Figure 5.

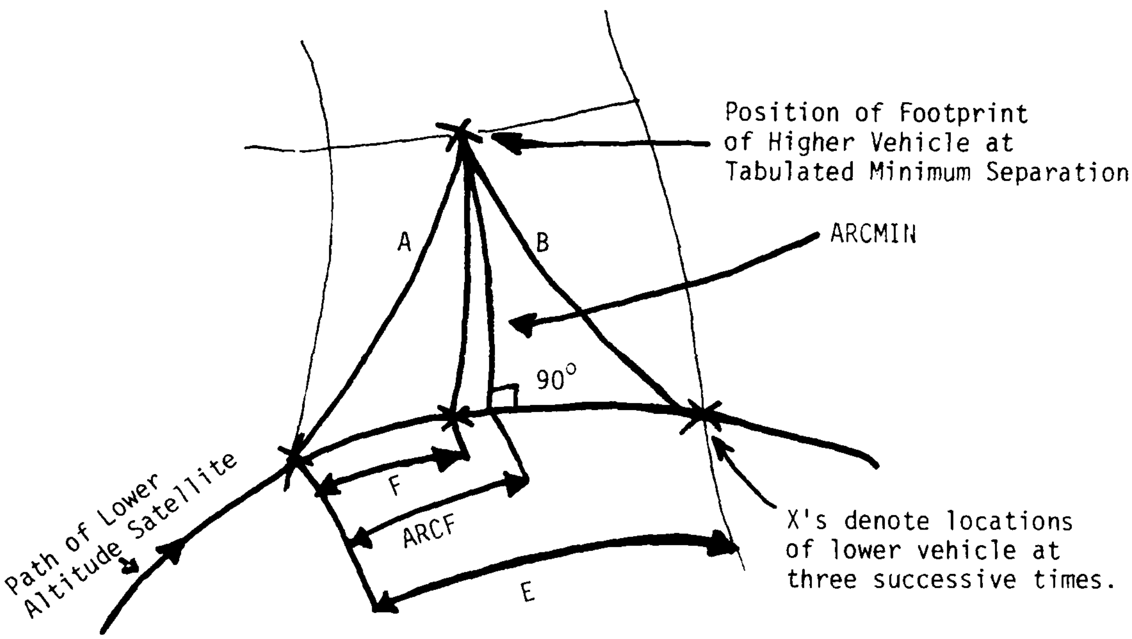

Figure 4. Geometry for Subroutine SEARCH

Card No.	Variable Name	Card Col.	Format	Variable Description
1	COEF(2)	1-20	2A10	Coefficient Label
1	TM	21-30	F10.2	Update Year
2	Brother	1-10	A10	Higher Altitude Satellite Name
2	Sister	11-21	A10	Lower Altitude Satellite Name

Table 5. Setup of Input Cards for Program FTPRNT

```
COEFFICIENT SET USED IGRF(1975)          UPDATED TO    19 0.00

          2265        FOOTPRINT       SCATHA       SATELLITE WITHIN FIVE DEGREES        SCATHA      CONJUNCTION
 DATE     HR MIN LAT  ELONG   ALT    HR MIN LAT  ELONG   ALT     HR MIN LAT  ELONG     ALT    HR MIN LAT  ELONG    ALT       MIN DIST(KM) L SHELL
 6/10/80  2 19 -52.4  150.5  574.9    2 18 -56.7  155.0  573.4    2 2  -47.3 151.0   574.6    2 19 -52.0  152.8   574.9     133.5             5.4

          2265        FOOTPRINT       SCATHA       SATELLITE WITHIN FIVE DEGREES        SCATHA      CONJUNCTION
 DATE     HR MIN LAT  ELONG   ALT    HR MIN LAT  ELONG   ALT     HR MIN LAT  ELONG     ALT    HR MIN LAT  ELONG    ALT       MIN DIST(KM) L SHELL
 6/10/80 11  2  68.6  206.8  565.1   11  1  72.5  217.7  567.1   11      63.8 207.7   563.2   11  2  68.2  211.8   565.1     154.5             7.5

          2265        FOOTPRINT       SCATHA       SATELLITE WITHIN FIVE DEGREES        SCATHA      CONJUNCTION
 DATE     HR MIN LAT  ELONG   ALT    HR MIN LAT  ELONG   ALT     HR MIN LAT  ELONG     ALT    HR MIN LAT  ELONG    ALT       MIN DIST(KM) L SHELL
 6/10/80 12 37  70.3  200.1  565.4   12 36  75.0  198.8  566.     12 3   68.2 187.9   563.5   12 37  71.7  192.4   565.4     355.5             7.7

          2265        FOOTPRINT       SCATHA       SATELLITE WITHIN FIVE DEGREES        SCATHA      CONJUNCTION
 DATE     HR MIN  AT  ELONG   ALT    HR MIN LAT  ELONG   ALT     HR MIN LAT  ELONG     ALT    HR MIN LAT  ELONG    ALT       MIN DIST(KM) L SHELL
 6/10/80 13 11 -57.5  154.7  565.2   13 10 -53.1  149.9  564.5   13 1  -63.2 146.2   566.    13 11 -56.6  148.2   565.2     411.5             7.8

          2265        FOOTPRINT       SCATHA       SATELLITE WITHIN FIVE DEGREES        SCATHA      CONJUNCTION
 DATE     HR MIN LAT  ELONG   ALT    HR MIN LAT  ELONG   ALT     HR MIN LAT  ELONG     ALT    HR MIN LAT  ELONG    ALT       MIN DIST(KM) L SHELL
 6/10/8  23 38  70.2  167.3  562.1   23 37  65.1  166.8  563.3   23 3   73.8 155.5   561.5   23 38  69.5  162.2   562.1     187.4             5.7

TAPE   NO. RECS.
  2       29
  3       293
```

Figure 5. Output Listing for Program FTPRNT

4.3.6 Program Restrictions and Timing

When the higher altitude satellite passes over the geomagnetic north or south pole, the magnetic field package MGFLD2 is unable to trace the field lines. Therefore, an internal check is made to determine when this condition exists. When it does, an approximaticn is made for conjugate point locations. Whenever a conjuncton is predicted using these approximations, a special message is written that these results may be unreliable.

The lower the altitude of the low altitude vehicle, the more rapidly its latitude/longitude coordinates vary with time. Thus, the lower the altitude, the smaller the time increment in the ephemeris calculation that is required to achieve a given accuracy in subroutine SEARCH. This translates into more data to be processed and, as a result, increased central processor times for lower altitude vehicles.

4.3.7 Control Cards and System Requirements

A typical series of control cards is as follows:

```
LBOB, T1000, CM75000.
ATTACH, TAPE1, IGRF, ID=GEDDES, MR=1.
ATTACH, TAPE2, SCATHA, ID=LEWIS, MR=1.
ATTACH, TAPE3, DMSP F2, ID=LEWIS, MR=1.
FTN, SL, R=3.
LDSET, PRESET=ZERO.
LGO, PL=20000.
```

A typical FTPRNT run consumes 1000 seconds of central processor time and requires 65K octal core memory.

4.4 Program Foot

4.4.1 Objective

The conducting path formed by the magnetic field line intersecting the SCATHA vehicle is capable of conducting currents down to each of the conjugate footprints in the lower ionosphere. Here, if ionization produced by solar radiation is present, the conducting channel can extend horizontally in the lower ionosphere. It is of interest to examine the solar illumination condition at these footprints to determine whether this ionospheric conduction mechanism is available. FOOT has been developed to make this determination.

4.4.2 Approach

Figure 6 illustrates the flow of operations for program FOOT. The satellite ephemeris is accepted in LOKANGL TAPE3 format. Determination of footprint location can be made using either of two magnetic field packages: MGFLD2 or BFLD. The latter uses the Olson-Pfitzer magnetic field model. The advantage claimed for this model is that the magnetic field is represented more realistically at the higher altitudes where currents due to particle flow (rather than Earth core effects) predominantly determine the field.

With the latitude, longitude, and altitude of the conjugate footprints available, Subroutine SOLLUN is called to evaluate the solar elevation angle at these locations. A simple correction is then made to account for refraction.

4.4.3 Input/Output

The input card setup for FOOT is shown in Table 6. Table 7 illustrates a typical set of control cards for this program. A sample output listing is shown in Table 8.

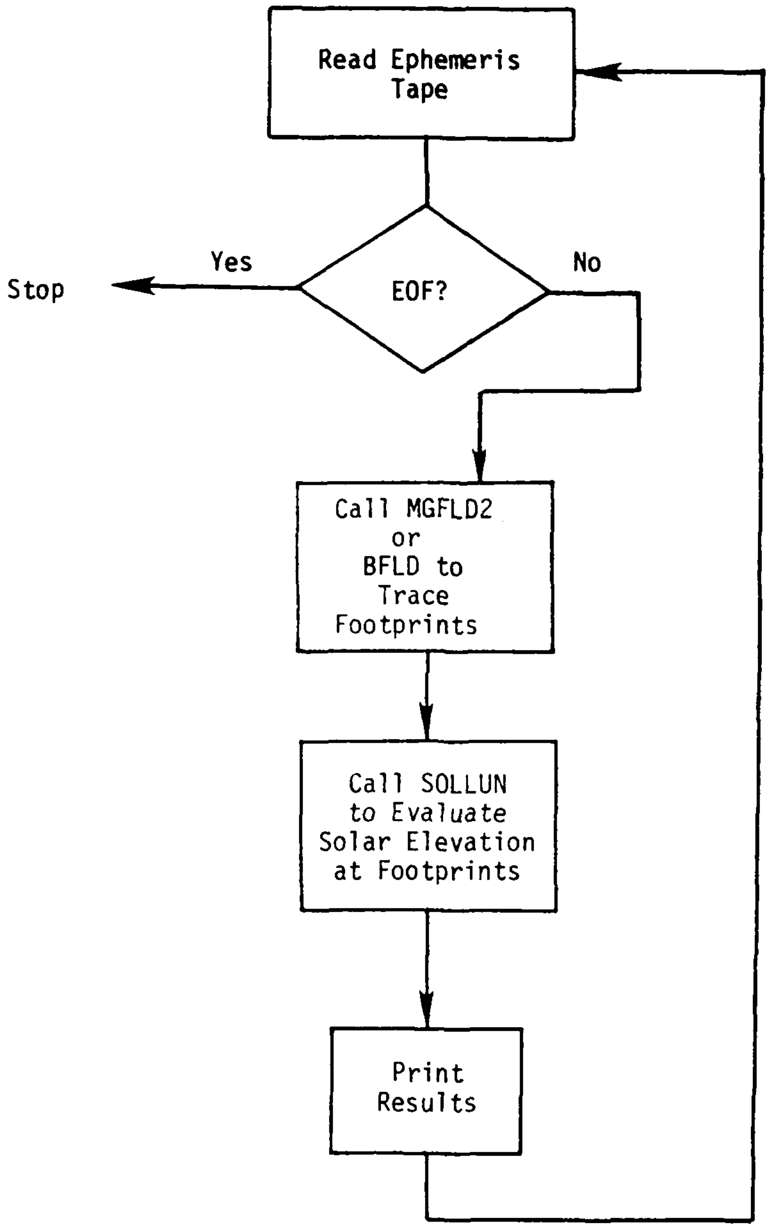

Figure 6. Flow of Operations for FOOT

Card No.	Variable	Format	Description
1	IOPT	I3	Selects Mag Field Model 0 = MGFLD2 1 = OLSON-PFITZER
2	COEF (2)	2A10	COEF Label
	TM	F10.2	Update Year

Table 6. Format of Input Cards for Program FOOT

```
OBERG, T100, CM120000.

ATTACH, TAPE2, FOOT, ID = OBERG

ATTACH, XX, IORLIB, ID = WEBER, MR = 1.

LIBRARY, XX.

ATTACH, TAPE1, IGRF75, ID = WEBER, MR = 1.

FTN.

LDSET, PRESET = ZERO.

LGO.
```

Table 7. Typical Sequence of Control Cards for Program FOOT

COEFFICIENT ET USED IGRF(1 ?9)   UPDATED TO   1976.0

NOTE SOLAR HORIZON ANGLE EXTENDS FROM 0 (WHEN SUN-EARTH'S LIMB-CONJUGATE PT. ARE COLINEAR) TO [illegible] REFRACTION (AT ZENITH)
+1=OPPOSITE MAGNETIC HEMISPHERE   -1=SAME MAGNETIC HEMISPHERE

DATE	HR	MN	SC	SATELLITE LAT	SATELLITE ELONG	SATELLITE ALT	+1 CONJUGAT PTS. 100.00 KM LAT	+1 ELONG	-1 LAT	-1 ELONG	SOLAR ELEV ANGLE (DEG) +1	SOLAR ELEV ANGLE (DEG) -1	L SHELL
10/17/76	3	24	0.	-83.[illegible]	[illegible]	12[illegible]	60.673	296.048	-60.767	32[illegible]	16.[illegible]	21.0[illegible]	[illegible]
10/17/76	3	24	5.	-83.7[illegible]	[illegible]	12[illegible]	60.516	296.256	-60.820	324.356	17.024	21.277	9.25
10/17/76	3	24	10.	-83.747	32[illegible]	1283.736	60.431	295.883	-60.836	320.043	17.4[illegible]	21.5[illegible]	9.21
10/17/76	3	24	15.	-83.7[illegible]	321.[illegible]	1282.[illegible]	60.276	29[illegible].035	-60.034	315.716	17.755	21.755	9.17
10/17/76	3	24	20.	-83.7[illegible]	31[illegible].651	1280.725	60.043	294.572	-60.014	311.416	16.167	21.994	9.12
10/17/76	3	24	25.	-83.7[illegible]	31[illegible].[illegible]2	1279.170	59.955	294.[illegible]31	-59.777	307.150	16.47[illegible]	22.2[illegible]3	9.[illegible]
10/17/76	3	24	30.	-83.77	313.[illegible]	1277.604	59.865	293.631	-59.723	303.075	16.721	22.472	9.03
10/17/76	3	24	35.	-83.7[illegible]	311.39[illegible]	127[illegible]	59.672	292.955	-56.653	299.119	19.1[illegible]1	22.711	8.99
10/17/76	3	24	40.	-83.7[illegible]1	3[illegible]	1274.435	59.525	292.432	-5[illegible].568	295.334	19.432	22.95[illegible]	[illegible]
10/17/76	3	24	45.	-83.[illegible]1	3[illegible]	127[illegible].[illegible]72	59.466	292.076	-5[illegible].469	291.745	19.623	23.159	[illegible]
10/17/76	3	24	50.	-83.[illegible]41	304.[illegible]	1271.[illegible]27	59.273	291.426	-5[illegible].356	28[illegible].3[illegible]1	20.016	23.42[illegible]	[illegible]
10/17/76	3	24	55.	-83.[illegible]1	301.[illegible]	12[illegible]	59.123	29[illegible].923	-5[illegible].233	285.186	20.222	23.667	8.78
10/17/76	3	25	0.	-83.[illegible]11	29[illegible].708	1267.95[illegible]	59.078	290.615	-5[illegible].198	282.218	20.455	23.907	[illegible].73
10/17/76	3	25	5.	-83.4[illegible]	297.[illegible]	12[illegible].259	5[illegible].837	290.613	-5.554	275.451	20.[illegible]	24.146	8.67
10/17/76	3	25	10.	-83.3[illegible]2	295.37[illegible]	12[illegible].635	58.745	289.563	-5.[illegible]1	27[illegible].277	21.140	24.385	[illegible].61
10/17/76	3	25	15.	-83.244	293.27[illegible]	12[illegible].[illegible]0	58.697	28[illegible].277	-5.641	274.485	21.398	24.625	8.55
10/17/76	3	25	20.	-83.1[illegible]	291.24[illegible]	1261.273	58.5[illegible]	288.725	-5.473	272.263	21.64[illegible]	24.864	[illegible]
10/17/76	3	25	25.	-83.0[illegible]3	28[illegible].27[illegible]	12[illegible].573	58.356	288.256	-5.299	270.2[illegible]	21.[illegible]	25.104	[illegible].44
10/17/76	3	25	30.	-82.9[illegible]	287.[illegible]6	1257.[illegible]2	58.319	288.052	-5.120	26[illegible].[illegible]83	22.[illegible]64	25.343	8.37
10/17/76	3	25	35.	-82.771	28[illegible]	1256.135	58.136	287.570	-4.936	26[illegible].50[illegible]	22.364	25.583	[illegible].31
10/17/76	3	25	40.	-82.6[illegible]4	283.74[illegible]	1254.404	58.056	287.700	-4.747	26[illegible].[illegible]41	22.556	25.822	[illegible].25
10/17/76	3	25	45.	-82.4[illegible]	2[illegible].[illegible]3[illegible]	1252.657	57.941	286.5[illegible]	-4.554	263.296	22.796	26.062	[illegible].19
10/17/76	3	25	50.	-82.34[illegible]	2[illegible]1.3[illegible]	12[illegible].[illegible]99	57.775	286.526	-4.358	261.254	23.[illegible]7[illegible]	26.3[illegible]	8.12
10/17/76	3	25	55.	-82.164	279.794	1249.126	57.753	286.369	-4.150	260.[illegible]	23.159	26.542	[illegible]
10/17/76	3	26	0.	-82.[illegible]3	277.[illegible]	1247.746	57.559	285.902	-3.955	259.246	23.403	26.7[illegible]2	7.99
10/17/76	3	26	5.	-81.[illegible]	275.[illegible]07	1245.553	57.429	285.5[illegible]	-3.750	25[illegible]	23.705	27.[illegible]2	7.93
10/17/76	3	26	10.	-81.[illegible]	274.79	1243.747	57.364	285.357	-3.542	25[illegible].[illegible]1	23.853	27.262	7.86
10/17/76	3	26	15.	-81.5[illegible]	27[illegible].[illegible]47	124[illegible].930	57.150	284.[illegible]	-3.372	255.[illegible]	24.147	27.502	7.79
10/17/76	3	26	20.	-81.327	271.74	1240.102	57.121	284.761	-3.120	254.943	24.273	27.742	7.73
10/17/76	3	26	25.	-81.1[illegible]	2[illegible]	123[illegible].262	5[illegible].9[illegible]6	284.[illegible]	-2.306	254.021	24.53[illegible]	27.[illegible]2	7.[illegible]
10/17/76	3	26	30.	-80.[illegible]	2[illegible]	123[illegible].410	56.816	284.072	-2.650	253.151	24.774	28.222	7.[illegible]
10/17/76	3	26	35.	-80.7[illegible]	2[illegible].157	1234.547	56.705	283.[illegible]1	-2.473	252.325	24.[illegible]	28.4[illegible]3	7.52
10/17/76	3	26	40.	-80.5[illegible]	267.[illegible]	1232.672	56.573	283.4[illegible]	-2.254	251.551	25.193	28.7[illegible]	7.45
10/17/76	3	26	45.	-8[illegible].3[illegible]	2[illegible]	1230.786	56.4[illegible]	283.[illegible]	-2.134	25[illegible].[illegible]14	25.345	28.944	7.[illegible]
10/17/76	3	26	50.	-8[illegible].162	26[illegible].[illegible]7	122[illegible]	56.335	282.559	-1.612	250.114	25.573	29.1[illegible]4	7.3[illegible]
10/17/76	3	26	55.	-79.9[illegible]	263.[illegible]7	122[illegible].960	56.191	282.[illegible]35	-1.530	24[illegible].45[illegible]	25.[illegible]5	29.4[illegible]	7.2[illegible]
10/17/76	3	27	0.	-79.7[illegible]	263.[illegible]	122[illegible].060	56.142	282.457	-1.366	24[illegible].[illegible]1[illegible]	25.94[illegible]	29.665	7.18
10/17/76	3	27	5.	-79.5[illegible]	2[illegible].1[illegible]1	122[illegible].1[illegible]	55.944	282.[illegible]74	-1.141	24[illegible].[illegible]16	26.240	29.906	7.11
10/17/76	3	27	10.	-79.325	2[illegible]	1221.186	55.845	281.845	-0.916	247.84[illegible]	26.411	30.147	7.04
10/17/76	3	27	15.	-79.11[illegible]	2[illegible].44[illegible]	121[illegible].232	55.769	281.[illegible]54	-0.[illegible]9	247.054	26.550	30.3[illegible]	6.97
10/17/76	3	27	20.	-78.[illegible]2	25[illegible]	121[illegible].387	55.560	281.[illegible]14	-0.461	246.570	26.641	30.[illegible]	[illegible].90
10/17/76	3	27	25.	-78.672	2[illegible]	121[illegible].291	55.418	281.[illegible]54	-0.233	24[illegible].[illegible]9	27.[illegible]4	30.[illegible]70	[illegible].[illegible]3
10/17/76	3	27	30.	-78.4[illegible]0	25[illegible].10	1217.[illegible]04	55.3[illegible]	280.[illegible]	-0.004	245.5[illegible]9	27.226	31.111	6.76
10/17/76	3	27	35.	-78.227	257.[illegible]	121[illegible].[illegible]5	55.211	280.[illegible]	-79.774	245.13[illegible]	27.367	31.352	6.7[illegible]
10/17/76	3	27	40.	-78.[illegible]1	25[illegible]	12[illegible].396	55.073	280.[illegible]91	-79.544	244.[illegible]	27.592	31.593	[illegible].[illegible]3
10/17/76	3	27	45.	-77.774	[illegible]	12[illegible].[illegible]	54.859	280.[illegible]1	-79.313	244.2[illegible]	27.[illegible]	31.835	[illegible]
10/17/76	3	27	50.	-77.5[illegible]	2[illegible]	12[illegible].245	54.753	279.[illegible]24	-79.0[illegible]1	243.[illegible]7	2[illegible]	32.076	[illegible]
10/17/76	3	27	55.	-77.316	25[illegible].74	12[illegible].203	54.639	279.[illegible]	-78.849	243.4[illegible]	28.249	32.317	[illegible]
10/17/76	3	28	0.	-77.[illegible]	254.1[illegible]	1211.150	54.534	279.[illegible]74	-78.[illegible]	24[illegible]	2[illegible].42[illegible]	32.5[illegible]	[illegible]
10/17/76	3	28	5.	-76.851	253.547	1209.[illegible]	54.372	279.[illegible]	-78.362	242.724	25.661	32.[illegible]	[illegible]

Table 8. Printout of Solar Elevation Angle at Footprints of S3-2 Satellite

4.5 Astro-Geophysical Data Display

4.5.1 Introduction

A variety of astro-geophysical (AG) data consisting of the time variation of parameters which depict the state of the magnetosphere are collected by the Air Force Global Weather Center (GWC) and forwarded to AFGL for geophysical analyses. The data are assembled onto tape at GWC using a 36-bit word UNIVAC 1110 computer. The data are unpacked, converted to 60-bit words for the CDC 6600, and displayed on microfiche.

4.5.2 AG Data Tape Convention

The AG data is written on a 7-track tape by a UNIVAC computer. The following definitions apply: 36 bits = 12 octal characters = 6 field data characters = 1 word. The data is written in card images in field data format; see Table 9 for the octal to character conversion. There are 70 files on the tape (7 days X 10 data types). Each file ends with a @EOF word. Two control words appear at the beginning of the tape and one at the very end, following the last @EOF. In addition, each card image is preceded by a control word. These card control words are of the format

00AABB100000

where

AA = octal number of words in the following card image
BB = octal number of words in the preceding card image

The first card image on the first file of the tape is
THIS TAPE CREATED ON MMDDYY AT HHMMSS BY AFGWC FOR SAMTEC SCATHA PROJECT
This statement is followed by the card image
DDMMYY
which gives the date on which the data on the next 10 files was taken.
Similarly the 11th, 21st, 31st...files are also preceded by a date word.
If the tape was created on Sep 9, the date on the first file will be Sep 8, the date on the 11th file will be Sep 7, and so on.

OCTAL	UNIVAC CHAR	OCTAL	UNIVAC CHAR
00	@	40	)
01	[	41	-
02	]	42	+
03	#	43	<
04	Δ	44	=
05	SP	45	>
06	A	46	&
07	B	47	$
10	C	50	*
11	D	51	(
12	E	52	%
13	F	53	:
14	G	54	?
15	H	55	!
16	I	56	,
17	J	57	/
20	K	60	0
21	L	61	1
22	M	62	2
23	N	63	3
24	O	64	4
25	P	65	5
26	Q	66	6
27	R	67	7
30	S	70	8
31	T	71	9
32	U	72	'
33	V	73	;
34	W	74	/
35	X	75	.
36	Y	76	
37	Z	77	≠

Table 9. Octal to Character Conversion (UNIVAC)

The ten data types (files) are:

(1) Astrogeophysical Data Base (AGDB) code type 10 (Raw Magnetometer Data)
(2) AGDB code type 11 (3Hr Ap)
(3) AGDB code type 22 (AK Values)
(4) AGDB code type 20 (Q index)
(5) GOES magnetometer data (Veh 1)
(6) GOES magnetometer data (Veh 2)
(7) GOES particle data (Veh 1)
(8) GOES particle data (Veh 2)
(9) CPA particle data (Veh 6)
(10) CPA particle data (Veh 4)

Figure 7 illustrates the organization of sequential files on the AG tapes. Data for the most recent day (i.e., the seventh) comes first. This data is contained in ten data files, one for each data type. Next (i.e., the second row of the matrix) come the ten files for the next to last day. These files are numbered eleven through twenty, inclusive. This pattern repeats until all ten files for the earliest day have been covered. (They are numbered 61 through 70). As an example of the use of the matrix, observe that the file number for GOES particle data (Vehicle 2) for the second day is 58. Note that, although data for individual days occurs in inverse chronological order on the tape, the data (of a given type) for each day proceeds in normal chronological order.

Two types of tapes are produced by GWC: a type 1 tape (old format) and a type 2 tape (new format). Type 1 tapes have variable image lengths which are allowed to span two physical records. Multiple AG files within records can also occur since an @EOF does not correspond to a tape EOR.

Type 2 tapes have uniform blocking of 15 images per tape record. The first image in each record is 13 36-bit words and is blank filled. The remaining 14 images are 14 36-bit words. After an @EOF the rest of that image and record are blank filled. Therefore, the next AG file starts with the second image of the next record.

DATA TYPE

DAYS	A/G								CPA	
	1	2	3	4	5	6	7	8	9	10
7	1	2	3	4	5	6	7	8	9	10
6	11	12	13	14	15	16	17	18	19	20
5	21	22	23	24	25	26	27	28	29	30
4	31	32	33	34	35	36	37	38	39	40
3	41	42	43	44	45	46	47	48	49	50
2	51	52	53	54	55	56	57	58	59	60
1	61	62	63	64	65	66	67	69	69	70

Figure 7. Sequential File Matrix

4.5.3 Convert UNIVAC to CDC Code

The physical AG Tape record length is 224 36-bit words in a packed configuration. Each 6-bit byte is unpacked from a bit stream. Character codes are formed and examined for @EOF. Thru a selection of program routines, the UNIVAC equivalent words are formed and arrays of 60-bit CDC words (designated MW in the software) are unpacked. Table 10 shows the bit locations for 36 bit packed words used in Tables 11-14. These tables summarize the word definitions, MW array numbers, the 6-bit words, and provide a reference to the subroutine in Program (AGDATA) which lists the data as a function of time.

The breakdown of the GOES magnetometer data (File 5 + 6) and GOES particle data (File 7 + 8) are shown in Tables 15 and 16. Files 5 + 7 are for Vehicle 1 data and files 6 + 8 for Vehicle 2 data. Each of these files consists of an array of words for six ten minute periods or 1 hour's cycle worth of data. For file 5 + 6 a cycle is 56 words; file 7 + 8 is 92 words. The bit packing for each of these files is identical.

The format and the content for the CPA particle data (Files 9 + 10) differs in that all the data is decoded as decimal numbers. Table 17 is a summary of the energy range of the 57 channels of CPA data.

H1 = bits 1-1	S2 = bits 7-12
H2 = bits 19-36	S3 = bits 13-18
T1 = bits 1-12	S4 = bits 19-24
T2 = bits 13-24	S5 = bits 25-30
T3 = bits 25-36	S6 = bits 31-36
Q1 = bits 1-9	W = bits 1-36
Q2 = bits 10-18	H : half word
Q3 = bits 19-27	T : third word
Q4 = bits 28-36	Q : quarter word
S1 = bits 1-6	S : sixth word
	W : full word

Table 10. Bit Definitions for Packed Words

		MW Array	6 bit word #	
WORD 1:	H1 = Word Count = 9	1	I+6	1st Image
	S4 = Day	2		
	S5 = Hour	3		
	S6 = Min	4		
WORD 2:	H1 = Code Type = 10	5	I+18	
	H2 = AFGWC Station No.	6		
WORD 3:	W = 0			
WORD 4:	W = WMO Number	7	I+42	
WORD 5:	Q1 = Year (00-99)	8	I+54	
	Q2 = Month	9		
	Q3 = Status of Report	10		
	Q4 = Processing Status	11		
WORD 6:	H1 = XMIN	12	I+66	
	H2 = YMAX	13		
WORD 7:	H1 = YMIN	14	I+6	2nd Image
	H2 = YMAX	15		
WORD 8:	H1 = ZMIN	16	I+18	
	H2 = ZMAX	17		
WORD 9:	H1 = MAX GAMMA	18	I+30	
	Q3 = ak value	19		
	Q4 = k value	20		

Table 11. CODE TYPE 10 (Magnetometer Data) - Subroutine FILE 1

		MW Array	6 bit word #
WORD 1:	H1 = Word Count = 5	1	I+6
	S4 = Day	2	
	S5 = Hour	3	
	S6 = Min	4	
WORD 2:	H1 = Code Type = 11	5	I+18
	H2 = AFGWC Station No.	6	
WORD 3:	W = 0		
WORD 4:	H1 = (2 digit year) *100 + Month	7	I+42
	H2 = 24 hr ap	8	
WORD 5:	H1 = 3 hrly ap	9	I+54
	H2 = Kp	10,11,12	

Table 12. CODE TYPE 11 (Geomagnetic Indices) - Subroutine FILE 2

		MW Array	6 bit word #	
WORD 1:	H1 = Word Count = 11	1	I+6	1st Image
	S4 = Day	2		
	S5 = Hour	3		
	S6 = Min	4		
WORD 2:	H1 = Code Type = 22	5	I+18	
	H2 = AFGWC Station No.	6		
WORD 3:	W = 0			
WORD 4:	W = WMO Number	7	I+42	
WORD 5:	Q1 = Year	8	I+54	
	Q2 = Month	9		
	Q3 = AK Value	10		
	Q4 = Status = 0	11		
WORD 6	Q1 = K value of First 3 Hr Period	12	I+66	
	Q2 = K value of Second 3 Hr Period	13		
	Q3 = K value of Third 3 Hr Period	14		
	Q4 = K value of Fourth 3 Hr Period	15		
WORD 7	Q1 = K value of Fifth 3 Hr Period	16	I+6	2nd Image
	Q2 = K value of Sixth 3 Hr Period	17		
	Q3 = K value of Seventh 3 Hr Period	18		
	Q4 = K value of Eighth 3 Hr Period	19		
WORD 8	H1 = Indicator of Phenomena	20	I+18	
	H2 = Time of Phenomena	21		
WORD 9	H1 = Time of Min Gamma Value	22	I+30	
	H2 = Minimum Gamma Value	23		
WORD 10	H1 = Time of Instantaneous H	24	I+42	
	H2 = Instantaneous H (Gammas)	25		
WORD 11	H1 = 0	26	I+54	
	H2 = Big AK of AK	27		

Table 13. CODE TYPE 22 - (Geomagnetic Indices) Subroutine FILE 3

		MW Array	6 bit word #	
WORD 1:	H1 = Word Count = 10	1	I+6	1st Image
	S4 = Day	2		
	S5 = Hour	3		
	S6 = Min	4		
WORD 2:	H1 = Code Type = 20	5	I+18	
	H2 = 0	6		
WORD 3:	W = 0			
WORD 4:	H1 = Satellite ID	7	I+42	
	H2 = Rev Number	8		
WORD 5:	Equatorward Latitude (tenths)	9	I+54	
WORD 6:	Equatorward Longitude (tenths)	10	I+66	
WORD 7:	Equatorward Corrected Geomagnetic Latitude	11	I+6	2nd Image
WORD 8:	Corrected Geomagnetic Local Time	12	I+18	
WORD 9:	Q Index (Tenths)	13	I+30	
WORD 10:	T1 = H/J Data	14	I+42	
	T2 = Data Qualifier	15		
	T3 = Aurora Characteristic	16		

Table 14. CODE Type 20 - (Auroral Index) Subroutine FILE 4

Words 1-48 are data for six ten minute periods from eight data lines of the GOSMM code.

Words 1-6 Data line containing 5 minute averaged magnetic field total magnitude values valid on the hour and every 10 minutes during the following hour.

Words 7-12 Data line containing 5 minute averaged values of the x-component of the magnetic field in an earth-centered solar-ecliptic rectangular coordinate system having its x-axis pointed toward the sun, its z-axis pointed northward perpendicular to the ecliptic plane and its y-axis in the ecliptic plane.

Words 13-18 Data line containing similar 5 minute averages values of the y-component of the magnetic field.

Words 19-24 Data line containing 5 minute averaged values of the z component of the magnetic field.

Words 25-30 Data line containing standard deviations of the averaged total magnetic field magnitude for each report during the hour.

Words 31-36 Data line containing similar standard deviation values for the x-component of the magnetic field.

Words 37-42 Data line containing similar standard deviation values for the y-component of the magnetic field.

Words 43-48 Data line containing similar standard deviation values for the z-component of the magnetic field.

Words 1-48 are packed with the FLD function as follows:

0	13	17	27	29 35	Starting bit of field
Unused	Qual	Field	Sign	Power of 10	Data Contents

Word 49 Local time at sub-satellite point on the hour.
Word 50 Latitude sign (1 is for North, 2 for South)
Word 51 Latitude of sub-satellite point. (whole degrees)
Word 52 Longitude sign (1 is for West, 2 for East)
Word 53 Longitude of sub-satellite point. (whole degrees)
Word 54 Year-Month-Day of data for this hour (YYMMDD).
Word 55 Currently unused.
Word 56 Currently unused.

Table 15. GOES Magnetometer Data - Subroutine FILE 5

Words 1-84 are data for six ten minute periods from 14 channels of the GOSPP coded data.

	Particle Type	Energy Range	
Words 1-6	ELECTRONS	> 2	MEV
Words 7-12	PROTONS	0.8-4	MEV
Words 13-18	PROTONS	4-8	MEV
Words 19-24	PROTONS	8-16	MEV
Words 25-30	PROTONS	16-215	MEV
Words 31-36	PROTONS	36-215	MEV
Words 37-42	PROTONS	80-215	MEV
Words 43-48	PROTONS	215-500	MEV
Words 49-54	ALPHAS	4-10	MEV
Words 55-60	ALPHAS	10-16	MEV
Words 61-66	ALPHAS	18-56	MEV
Words 67-72	ALPHAS	71-150	MEV
Words 73-78	ALPHAS	167-245	MEV
Words 79-84	ALPHAS	340-392	MEV

Words 1-84 are packed with the FLD function as follows:

0	13	17	27	29	35	Starting bit of field
Unused	Qual	Field	Sign	Power of 10		Data Contents

Word 85 Local time on the hour.
Word 86 Latitude sign (1 is North, 2 for South)
Word 87 Latitude in degrees
Word 88 Longitude sign (1 is West, 2 is East)
Word 89 Longitude in degrees
Word 90 Year-Month-Day of data
Word 91 Unused.
Word 92 Unused.

Table 16. GOES Particle Data - Subroutine FILE 7

Satellite Look Ang	Particle Type	Energy Range	
+60 DEG	ELECTRONS	30 - 300 KEV	
+60 DEG	ELECTRONS	44 - 300 KEV	
+60 DEG	ELECTRONS	64 - 300 KEV	
+60 DEG	ELECTRONs	95 - 300 KEV	
+60 DEG	ELECTRONS	139 - 300 KEV	
+60 DEG	ELECTRONS	204 - 300 KEV	
+30 DEG	ELECTRONS	30 - 300 KEV	
SAT EQ	ELECTRONS	30 - 300 KEV	
SAT EQ	ELECTRONS	44 - 300 KEV	
SAT EQ	ELECTRONS	64 - 300 KEV	
SAT EQ	ELECTRONS	95 - 300 KEV	
SAT EQ	ELECTRONS	139 - 300 KEV	
SAT EQ	ELECTRONS	204 - 300 KEV	
-30 DEG	ELECTRONS	30 - 300 KEV	
-30 DEG	ELECTRONS	44 - 300 KEV	
-30 DEG	ELECTRONS	64 - 300 KEV	
-30 DEG	ELECTRONS	95 - 300 KEV	
-30 DEG	ELECTRONS	139 - 300 KEV	
-30 DEG	ELECTRONS	204 - 300 KEV	
-60 DEG	ELECTRONS	30 - 300 KEV	
-60 DEG	ELECTRONS	44 - 300 KEV	
-60 DEG	ELECTRONS	64 - 300 KEV	
-60 DEG	ELECTRONS	95 - 300 KEV	
-60 DEG	ELECTRONS	139 - 300 KEV	
-60 DEG	ELECTRONS	204 - 300 KEV	
	ELECTRONS	0.20 - 2.0 MEV	
	ELECTRONS	0.29 - 2.0 MEV	
	ELECTRONS	0.43 - 2.0 MEV	
	ELECTRONS	0.63 - 2.0 MEV	
	ELECTRONS	0.98 - 2.0 MEV	
	ELECTRONS	1.36 - 2.0 MEV	
	PROTONS	50 - 500 KEV	
	PROTONS	63 - 500 KEV	
	PROTONS	80 - 500 KEV	
	PROTONS	100 - 500 KEV	
	PROTONS	126 - 500 KEV	
	PROTONS	158 - 500 KEV	
	PROTONS	198 - 500 KEV	
	PROTONS	252 - 500 KEV	
	PROTONS	316 - 500 KEV	
	PROTONS	396 - 500 KEV	
	PROTONS	0.3 - 0.4	(0.35) MEV
	PROTONS	0.4 - 0.53	(0.46) MEV
	PROTONS	0.53 - 0.71	(0.62) MEV
	PROTONS	0.71 - 0.94	(0.82) MEV
	PROTONS	0.94 - 1.25	(1.1) MEV
	PROTONS	1.25 - 1.66	(1.46) MEV
	PROTONS	1.66 - 2.80	(1.93) MEV

Table 17. CPA Particle Data-Subroutine FILE 9

Particle Type	Energy Range			
PROTONS	2.80	-	4.73	(3.76) MEV
PROTONS	4.73	-	8.00	(6.36) MEV
PROTONS	8.00	-	13.5	(10.8) MEV
PROTONS	13.5	-	22.8	(18.2) MEV
PROTONS	22.8	-	33.2	(28.0) MEV
PROTONS	33.2	-	48.4	(40.8) MEV
PROTONS	48.4	-	70.6	(59.5) MEV
PROTONS	70.6	-	103.	(86.8) MEV
PROTONS	103.	-	150.	(126.) MEV

Table 17. CPA Particle Data-Subroutine FILE 9 (continued)

4.5.4 AG Programs

Five Fortran programs process AG related information. Table 18 is a list of these programs along with a summary description of each.

PROGRAM	Core	Run Time (Sec)	DESCRIPTION
LOCZD	60K	500	Dump AG Tape (complete)
LOCZL	60K	2	List AGMMDD Tapes
LOCZR	60K	500	Reformat AG Type 1 (old) create AG Type 2 (new) tape.
LOCZS	135K	1800	List data and produce microfiche plots from AG type 2 (new) tape
LOCZT	60K	2	Dump AG Tape (1st record) header

TABLE 18: AG Programs

Program LOCZS with its system of subroutines converts AGMMDD type 2 data tapes from UNIVAC formatted code to CDC code. From an input punched card, the number of days, the total number of files utilized, and file selection order is determined. An example of a file 1 chronological selection would be: 71, 61, 51, 41, 31, 21, 11, 1. As the AGMMDD tape is processed @EOF detection defines the file partitions. Thus all AG data and file markers with the exception of the CPA data is contained in a single file. The CPA data is placed in 14 addressable files. By volume 84% of the AG data is CPA particle data. This file structure system permits a considerable run time savings since the search for data is greatly reduced. Figure 8 illustrates the flow of information for Program LOCZS.

Through a system of frames which contain up to four plots each, 190 plots are contained in 53 frames. A summary of these plots is shown in Table 19. AG data files of the same type must be chosen sequentially with no restriction as to chronological ordering. If a file is empty the day counter will not be activated because the AG tape contains 70 files, full or not. Since the day counter actually checks EOF status, a frame will be produced only if data is available to be plotted.

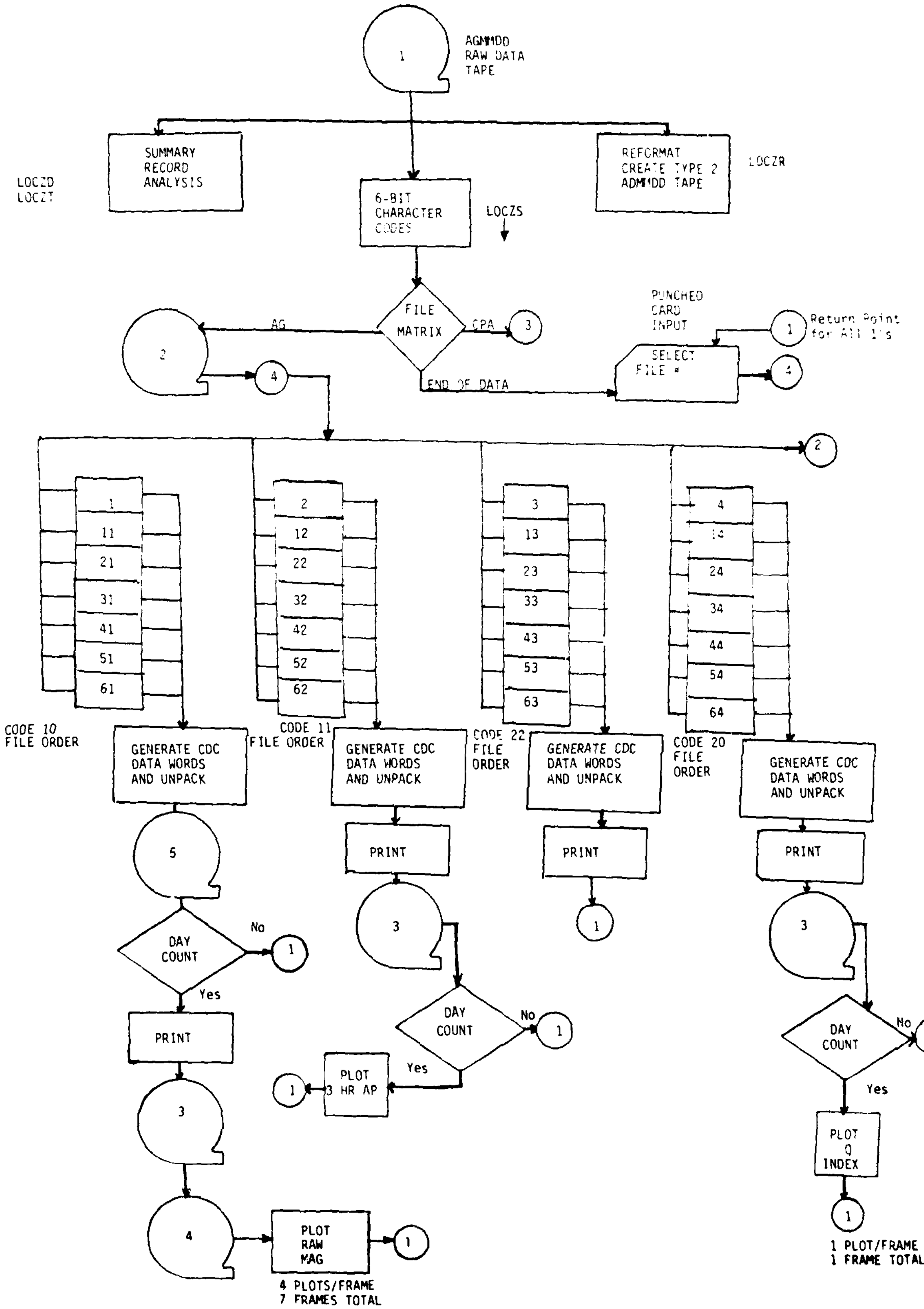

Figure 8a. Flow Chart for LOCZS

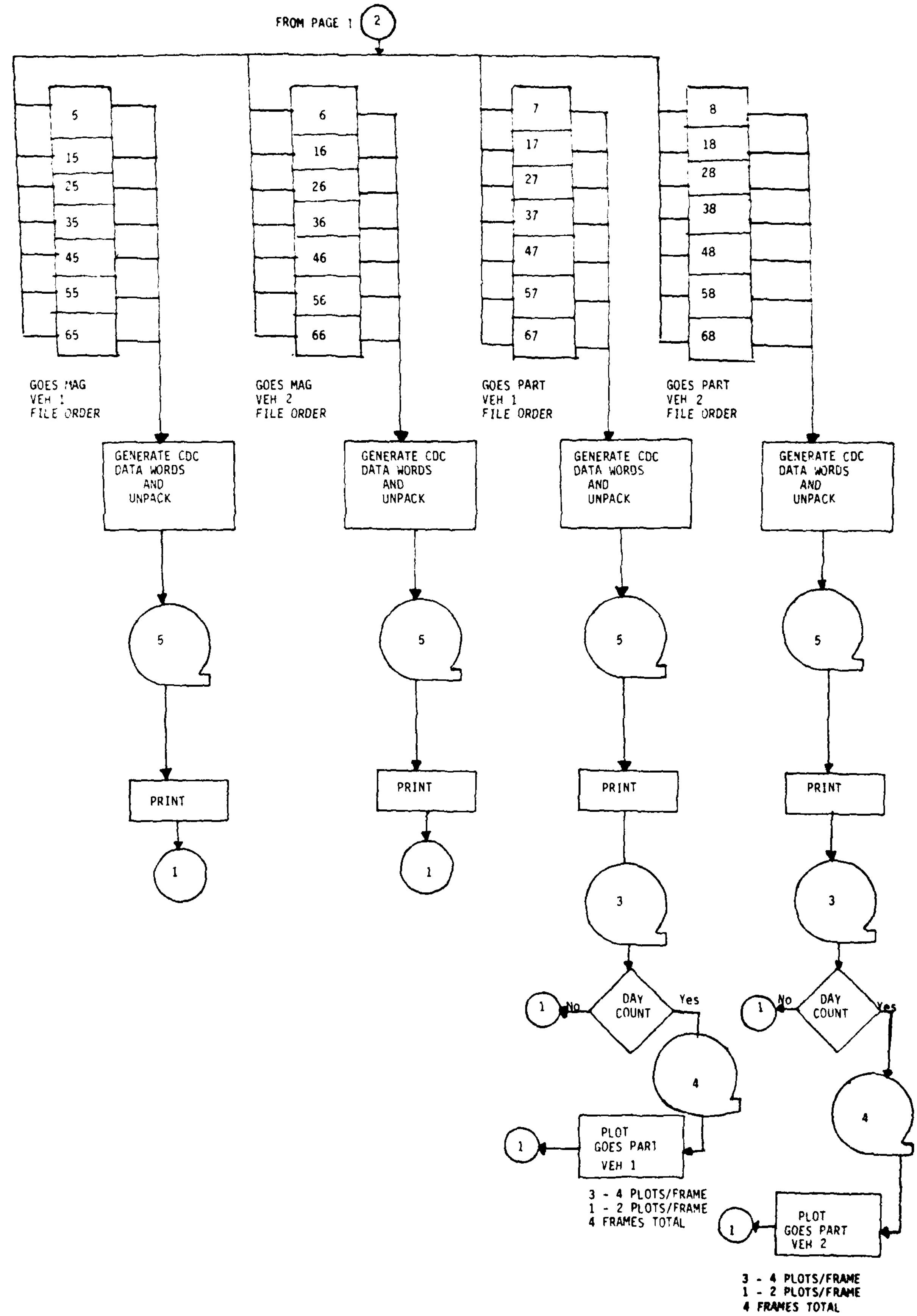

Figure 8b. Flow Chart for LOCZS (Continued)

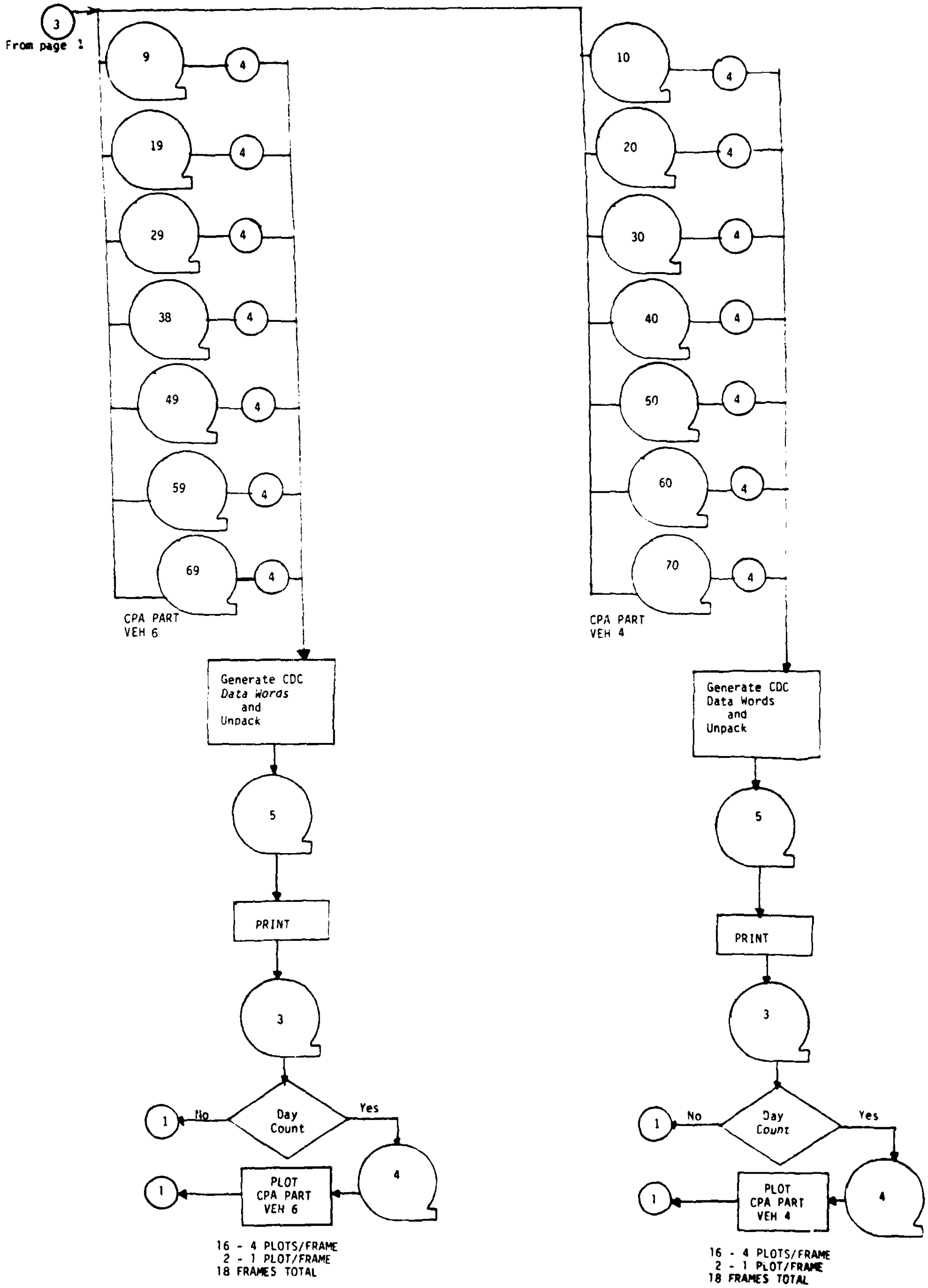

Figure 8c. Flow Chart for LOCZS (Continued)

AG File #	Frames	Plots/Frame	Description
1	7	4	Raw Magnetometer Data
2	1	1	3 Hr Ap
4	1	1	Q Index
7	3	4	GOES Particle Data (Vehicle 1)
	1	2	
8	3	4	GOES Particle Data (Vehicle 2)
	1	2	
9	14	4	CPA Particle Data (Vehicle 6)
	1	1	
	2	4	Angular Distribution and High/Low Energy Summaries
	1	1	
10	14	4	CPA Particle Data (Vehicle 4)
	1	1	
	2	4	Angular Distribution and High/Low Energy Summaries
	1	1	

TABLE 19. AG Plot System

For most types of data, the values plotted are essentially the raw numbers unpacked from the data tape. Magnetometer data, though, is an exception. Table 11 shows that both maximum and minimum values are reported for each of the X, Y, and Z coordinates. This data occurs at the rate of one set of values every 90 minutes. The value plotted at any given time is derived from both the value quoted at that time and the value corresponding to the time 90 minutes earlier. The minimum is taken for the minima at these two times. Similarly, the maximum is taken for the two maxima. The number plotted is obtained by subtracting the resulting minimum of minima from the corresponding maximum of maxima. This procedure is followed for each of the three rectangular components of the field.

Programs LOCZD and LOCZT are similar in that each examines an AG tape as to type and creation date. LOCZD has additional logic that checks an entire tape for overall file content, and has an option for an octal dump. LOCZT, on the other hand, checks only the first record for type , creation date, and file information to delineate the AGMMDD tape label, where MM is the month and DD is the day of the first chronological file.

Program LOCZL lists the AGMMDD tapes at AFGL along with their inclusive file dates and types.

Program LOCZR creates an AG type 2 (new) tape from an AG type 1 (old) tape. Typically, type 2 tapes are received at AFGL weekly, despite the fact that type 1 processing is available. A parallel programming task was abandoned when it was decided not to continue type 1 reduction. It was determined that the type 2 tape format was more conducive to efficient chronological sorting. However, when only the type 1 tape was received, and since GWC retains AG data for only 60 days, program LOCZR provides a means to reduce significantly more data than would otherwise be possible.

4.6 References

1. Hess, W.N. "The Radiation Belt and Magnetosphere," Blaisdell, Waltham, MA, 1968.

2. Alfven, H., and C.-G. Falthammar, "Cosmical Electrodynamics," 2nd Ed, Oxford Univ. Press, London, 1963.

5.0 Rocket Trajectory System

This section discusses updates made to the rocket trajectory system since preparation of a comprehensive report and user's guide.[1] These changes include:

(1) Addition of dynamics models for new vehicles;

(2) Upgrading of Ft.Churchill boresight directional corrections and application of same to other radars;

(3) Conversion of White Sands trajectory reports to AFGL TAPE4 format.

5.1 Rocket Dynamics Models

Thrust, mass and drag characteristics of several new vehicles have been added to DRIVEB since publication of Ref. 1. These are listed in Table 1. Test integration and filtering runs resulted in adjustments in some cases.

5.1.1 Multiple Modules and Thrust Angles

In some cases the vehicle separates into modules, which are then to be analyzed individually by DRIVEB. Furthermore the separate module(s) may undergo attitude maneuvers resulting in thrusting at angles other than the velocity direction. An example of same is the ARIES vehicle from which the payload separates 63 sec after launch. At 90 sec, there is further separation of payload into sensor and target, the latter of which thrusts at various angles off the velocity vector during the remainder of the flight. Furthermore the boost phase is known to have non-zero velocity-thrust angles. In this case the thrust direction has been defined by the angle from vertical. It is assumed to lie in the azimuthal plane of the flight.

The procedures for handling these are are follows: prior to separation, sensor and target modules are assigned the booster's dynamic model. Thus separate information for these models has been added only after separation.

Rocket	Key
Sergeant-Hydac	02
Nike-Orion	12
Taurus-Orion	13
Aries Sensor	26
Aries Target	27
Talos - Castor	51

Table 1. Dynamics Models for New Rockets

A special data array has been added to hold thrust angle as a piecewise linear function of time. This is applied to the booster initially and later to the target.

5.1.1.1 Suggestions for Improved Handling of Multiple Module Missions

The above procedure could result in a proliferation of models as multiple-module missions become more frequent. Furthermore separations could occur with finite velocity. One way to handle this latter occurrence is to build a short impulse into the thrust model (say, 1/2 sec in duration). This procedure has been employed in some cases not permanently built into the program. However this could use up valuable storage space in the model data array. More systematic procedures are suggested as follows.

Selective Tracking of Modules (Payloads or Booster) in DRIVEB.

1. Up to 5 modules including booster.

2. Specifications for each module.
   a) Number (1-5)
   b) Weight (with and without fuel), area, drag
   c) Alphanumeric identifier for thrust model (if any)

3. Separation specifications
   a) Time
   b) Contents of Vehicle #1 (module numbers)
   c) Contents of vehicle #2 (module numbers)
   d) Separation velocity (vehicle #1 - vehicle #2)

   Vehicle #1 will be the front vehicle.
   Vehicle #2 will be the back vehicle.

4. Thrust and angles for payload modules.

Logic:

1. For the selected module the following is saved after completion of each integraton step.

a) Separation times immediatedly before and after current time, for separations involving the module (TSEP1 and TSEP2)

b) Modules to which it is connected Mod (I), I=1, NMOD

c) Total Weight, drag and area of package and thrust model identifier

2. At each new step test to see if time is still between TSEP1 and TSEP2; if so compute forces and perform integration step in usual fashion; if not, update module information mentioned in step 1 and make velocity correction in accordance with specified separation velocity; then proceed with usual force computation.

5.2 *Boresight Corrections*

Corrections have been incorporated to account for directional differences between the RF beam and the mechanical axis of a radar.[2] The raw (azimuth and elevation) angles represent the mechanical axis direction, while the tracked target lies along the RF beam. Previously, corrections had been made to Ft. Churchill data only. These corrections were independent of the elevation angle of the radar and hence were accurate for low elevations only.

To determine the azimuth and elevation corrections in the general case we first define the unit vector components of the RF direction in the radar-fixed coordinate system:

$$x = \sin K \cos P$$
$$y = \cos K \cos P$$
$$z = \sin P$$

where K and P are the azimuth and elevation of the RF beam when the mechanical axis reads azimuth=elevation=0. Thus the radar-fixed y axis lies along the mechanical axis, the z axis points vertically upward when the mechanical elevation = 0, and x-y-z defines a right-handed coordinate system. The angles K and P can be found from plunge-and-rotate methods.[3] To obtain the RF azimuth and elevation in the general case we require the coordinate transformation from the radar-fixed system to the local-vertical system:

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{bmatrix} \cos A & \sin A & 0 \\ -\sin A & \cos A & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos E & -\sin E \\ 0 & \sin E & \cos E \end{bmatrix} \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

where A and E are the mechanical axis azimuth and elevation angles. The local vertical coordinates x', y', z' of the RF beam are related to the RF azimuth and elevation angles A' and E' by:

$$x' = \sin A' \cos E'$$
$$y' = \cos A' \cos E'$$
$$z' = \sin E'$$

Carrying out the required matrix multiplication and substituting for x, y, z from above results in

$$\cos E' \sin A' = \cos A \sin K \cos P + \sin A (\cos K \cos E \cos P - \sin E \sin P)$$

$$\cos E' \cos A' = -\sin K \cos P \sin A + \cos A (\cos E \cos K \cos P - \sin E \sin P)$$

$$\sin E' = \sin E \cos K \cos P + \cos E \sin P$$

Using the trigonometric identities for the sine and cosine of the sum of two angles it is found that

$$A' = A + t$$

$$\tan t = \frac{\sin K \cos P}{\cos K \cos (E + P) - (1-\cos K) \sin E \sin P}$$

$$\sin E' = \cos K \sin (E + P) + \cos E \sin P (1-\cos K)$$

Neglecting terms of 3rd order and higher in the angles K and P simplifies these expressions to

$$\tan t = \frac{\tan K}{\cos(E+ P)}$$

$$\sin E' = \cos K \sin (E + P)$$

These results are exact if either K or P is equal to zero, the latter of which is often the case. They have therefore been incorporated into DRIVEA.

It is therefore necessary to read DRIVEA input cards 5-7[1] regardless of radar range parameter ICODE, which is now used only to distinguish Eglin (ICODE = 1) from the others (ICODE = 2), for the purpose of adding Eglin's flight line direction to the Az angle.

5.3 WSMR Trajectory Report Conversion

White Sands Missile Range (WSMR) often makes available results of its radar data reduction on UNIVAC binary and BCD tapes.[4] It is often useful to compare these results with those obtained from the AFGL rocket trajectory system. To facilitate this procedure, software was developed for conversion of the WSMR 3x80 binary data to the AFGL rocket trajectory report (TAPE 4) format.[5] This software consists of two programs:

1. Program WSMRBIN, which creates an intermediate file containing geocentric position, velocity, and acceleration from a WSMR 3x80 binary tape;

2. Program FORGEN, which converts the file written by WSMRBIN to an AFGL rocket trajectory report tape, using an earlier format.[6] Raw data, residuals and covariances are omitted (zero-filled).

Program NEWFOR, which replaces FORGEN, provides these variables in the new format given in Ref. 1. The variables available are indicated in Table 2 (remaining words zero-filled). The input tape (TAPE2) as created by WSMRBIN) consists of the following:

Header:

HEAD (3-4) launcher latitude, longitude (W) (deg)
HEAD (5-6) radar latitude, longitude(W) (deg)
IHEAD (8-10) launch month, day, year
IHEAD (11) seconds UT launch time

Data Records:

GMT(sec) followed by geocentric position, velocity, and accleration vectors (km ,Km/sec, Km/sec^2), followed by altitude (Km).

The following card inputs are required:

Card 1 Cols 1-70(7A10) TITLE(1-7)
Card 2 Cols 1-20(2A10) DAT(5-6): Rocket id

TITLE(8) is left blank. The radar and launcher altitudes are set to 1.2312 Km.

Program WSMRBIN is a modification of program WSMR[7], an SUN library program which was written for conversion of WSMR's multi-radar 3x80 UNIVAC 1108 binary tapes. The input file (TAPE 13) is as described in Ref. 4, with the following provisos:

One header record per station plus one for multi-station solution if it exists. One 80 word data group per station per time line (+1 for multi-station solution if it exists), blocked in 3 groups per 3x80 physical record.

Four input cards are read, as described in Table 3. One binary output file is generated per station (plus one for multi-station solution) on tapes 2 thru 7 in the format previously discussed for input to NEWFOR.

Header record Word #	Symbol	Description
1-8	TITLE(1-8)	80 character alphanumeric id
9-10	DAT(1-2)	Run date, blank
18	DAT(4)	Launch date
19-20	DAT(5-6)	Rocket id
21-23	PROGID(1-3)	Program id for plotted output
24	HRAD	Radar altitude (Km)
25-27	RLODEG, RLOMIN, RLOSEC	Radar longitude (deg W, min, sec)
28-30	RLADEG, RLAMN, RLASEC	Radar latitude (deg N, min, sec)
31	AALT	Launcher altitude (Km)
32-34	ALODEG, ALOMIN, ALOSEC	Launcher longitude (deg W, min, sec)
35-37	ALADEG, ALAMIN, ALASEC	Launcher latitude (deg N, min, sec)
38	TLNCH	Launch time UT (sec)
43	DT	Computation time step size (sec)
44	TLI	Initial print time from launch
45	TLF	Final print time from launch)
46	TSKIP	Tape written every TSKIP secs

Table 2. WSMR Trajectory Report (AFGL Format)

Data records Word #	Symbol	Description
1	GMT	Universal time (sec)
2	TIME	Time after launch (sec)
4	RAG	Right ascension of Greenwich (rad)
5-7	P2(1-3)	Filtered geocentric pos. vector (km)
8-10	P2(4-6)	Filtered geoc. vel. vector (Km/sec)
11-13	P2(7-9)	Filtered geoc. acc. vector (Km/sec^2)
14-16	PVL(1-3)	Filtered launcher ref. pos. (Km)
17-19	PVL(4-6)	Filtered launcher ref. vel. (Km/sec^2)
20-22	PVL(7-9)	Filtered launcher ref. acc. (Km/sec^2)
23-25	OVL(1-3)	Filtered launcher ref. range, az, el (Km,deg)
26-28	OVL(4-6)	Filtered launcher ref. range, az, el rates (Km/sec, deg/sec)
65-67	OVR(1-3)	Same as wds. 23-25, but for radar
68-70	OVR(4-6)	Same as wds 26-28, but for radar
71-73	PVR(1-3)	Same as wds 14-16, but for radar
74-76	GPV(1-3)	Geodetic alt., long(W), lat. (Km, deg)
77	VR	Local velocity magnitude (Km/sec)
78,79	AZR, ELR	Azimuth, elevation, of local velocity vector (deg)
90	GRANGE	Ground range along spheriod (Km)
91	ACLMAG	Launcher ref. accel. magnitude (Km/sec^2)

Table 2. WSMR Trajectory Report (AFGL Format) Continued

Card No.	Variable Name	Card Col.	Format	Variable Description
1	IRKNO	1-10	A10	ROCKET NUMBER
1	ISTNO	11-15	I5	NUMBER OF RADAR STATIONS
1	STPTIM	16-29	F10.3	TIME (SEC GMT) to STOP PROCESSING
2	LMON	1-2	I2	MONTH OF LAUNCH
2	LDAY	4-5	I2	DAY OF LAUNCH
2	LYR	7-8	I2	YEAR OF LAUNCH
2	IHR	10-19	F10.4	HOUR OF LAUNCH
2	IMIN	20-29	F10.4	MINUTE OF LAUNCH
2	ISEC	30-39	F10.4	SECOND OF LAUNCH
2	IOPT	40	I1	1 = NO LISTING - TAPE OUTPUT 2 = LISTING - NO TAPE OUTPUT 3 = LISTING - TAPE OUTPUT
2	IMULT	41-42	I2	1 = MULTI-STATION SOLUTION ON TAPE ANY OTHER VALUE = NO MULTI-STATION ON TAPE
3	IROCNO	1-30	615	RADAR STATION ID's UP TO SIX INCLUDING 999 FOR MULTI-STATION SOLUTION IF PRESENT.
4	IO(1)-IO(40)	1-80	4012	WORD NUMBERS, IN 80 WORD DATA GROUPS, OF VARIABLES TO BE LISTED IN PRINT-OUT (MAXIMUM OF 40 ALLOWED)

Table 3. WSMRBIN Punched Card Input

5.4 References

1. Bhavnani, K. H., and Robinson, E.C., "Functional and Operational Advances in the AFGL Rocket Trajectory System I", AFGL-TR-79-0183, 1979.

2. Fike, R.M., "Trajectory Systems Comparison", Oklahoma State University Technical Report No. 4634-4, Appendix B, 1975.

3. Schonbein, W.R., "Analysis of Rocket Trajectory Data from Tracking Radars", AFCRL-72-0679, 1973.

4. WSMR Electronic Section Personnel, "ELDASY Electronic Data Reduction System," WSMR Technical Report, 1972.

5. Bass, J.N., Bhavnani, K.H., Kotelly, J.C., and Schwank, D.C., "Data Reduction Programs for MSMP", AFGL-TR-78-0313, 1978.

6. Logicon, Inc., "Analysis and Programming for Research in Physics of the Upper Atmosphere," Final Report, AFGL-TR-76-0231, 1976.

7. LaCroix, A., "WSMR 3x80 Tape Conversion," Contract No. F19628-76-C-0203, Project No. 0001, Task No. 00, Work Unit No. 00, Account/Problem No. 4904.

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